John H. Mills.

HEAT.

CIENCE AND PHILOSOPHY OF ITS PRODUCTION AND APPLICATION

TO THE

…ing and Ventilation of Buildings

THE ABSORBING AND TRANSMITTING POWER OF DIFFERENT

BOILER AND RADIATOR SURFACES

WITH STEAM AND WATER CIRCULATION.

VENTILATION

BY FANS AND WATER MOTORS WITH HYDRANT PRESSURE.

ALSO PLANS, TABLES AND DIAGRAMS OF EXPERIMENTAL WORK, AND RESULTS OF ACTUAL CONSTRUCTION.

BY JOHN H. MILLS.

VOLUME 1.

PRESS OF AMERICAN PRINTING AND ENGRAVING CO.,
BOSTON, MASS.

TO ARCHITECTS AND BUILDERS,

TO

ENGINEERS AND CONTRACTORS

OF

Steam and Water Heating Apparatus,

TO

TEACHERS, SUPERINTENDENTS OF PUBLIC BUILDINGS,

AND

TO ALL INTERESTED IN THE GENERATION AND APPLICATION OF HEAT,

THE FOLLOWING PAGES ARE RESPECTFULLY INSCRIBED

BY

THE AUTHOR.

BOSTON, March 17, 1886.

JOHN H. MILLS, ESQ., Buffalo, N. Y.

Dear Sir: Your favor of 15th inst., asking my permission to reproduce plates and diagrams illustrating combustion, originated and used by Professor E. W. Dimond in presenting my invention for burning fuel, came duly to hand.

You are at liberty to make such use as you may see fit of the "Chemistry of Combustion" in illustrating and presenting your forthcoming volume.

I most willingly grant your request. I would further say that I am glad to learn that you intend giving to the public the results of your experiments and practice in warming and ventilating buildings by both "direct" and "indirect" systems.

I know that your methods are original, and I believe them valuable. I shall be glad to see your tabulated statement of the results accomplished by your system of *mechanical ventilation* which I saw in operation in the public schools and at the State Insane Asylum, Buffalo, N. Y.

If the principles on which your book is based, and their intimate connection with the health of homes and the progress of civilization were understood, it would be sought more eagerly than any romance. Life and health have greater attractions than any fiction, and the chemical processes that build up and tear down the human system are more marvelous than Munchausen's wildest fancy. Chemistry is the science of immortality. Not the immortality of theology, but the immortality and indestructibility of every particle of matter. It is not atheism, but the sunshine of civilization. It teaches us how to make good bread and butter and the requisites of a healthy kitchen; how to forge steel and iron, to warm our houses, and to prevent disease.

Ventilation is the removing of noxious exhalations beyond the possibility of again entering the lungs. Every drop of blood in the system passes through the lungs twenty-eight times in one hour; and, if these exhalations again enter them, health must suffer and disease increase. One of our most eminent physicians, in an address to the people of the State, said that pure air was of more value for restoring the sick than any medicine he could give. An analysis of the air of the highlands of Scotland, as compared with that of the houses of London, led the government to *compel sanitary changes that reduced the death-rate from fifty-five to less than twenty-two per thousand.*

In our Public Garden stands a monument commemorating the discovery of the uses of ether for alleviating pain. It is of granite, senseless and cold, yet warmed by human sympathy. Pain yields to the physician's skill, and the sufferer sleeps with the confidence and trust of a child on its mother's breast. This monument, with its symbols of relief for suffering humanity, is a fitting representative of your work.

Pure air in that wholesome quantity that nature asks and pleads for prevents disease, while ether only conceals it beneath her insidious slumbers.

Whoever has warmed one home with pure air and properly ventilated it, has extended the field in which men, women, and children gather the fruits of happiness.

Wishing that your labors may meet with the success and appreciation that they so fully deserve, I remain,

Yours Very Respectfully

Sidney Smith

PREFACE.

HAVING published, in 1878, a treatise on the application of *steam* to heating buildings, which being well received, and still in demand, the writer has decided to supply additional copies of this circular, and at the same time to comply with the requests of friends to put in some permanent form the results of his later work and experiments in the general application of heat and heating appliances.

Twelve years devoted to invention, manufacture, the use of new machines and methods, may not be the requisite preparation, in a literary sense, for the production of a book largely in the domain of the sciences, but since the sciences to be of value must have a practical application, the record of such as have fallen under the writer's personal observation, with a compilation of the work, experiments and opinions of prominent Engineers, will, it is hoped, be acceptable, not alone to his friends and fellow workmen, but to the Architect, the Heating Engineer, and the individual who would build for himself or others a home worthy of the name.

In surrendering for a time other tools in favor of the pen, the writer avails himself of a long-desired opportunity of greeting his earlier and later friends, those individuals and companies, his first and later employers, whose ambition and desire for progress, prompted them to encourage experiment, and reward efforts to reach their own high standard of excellence in manufactures, in the arts, and their application to the problems of heating and ventilation.

As but a limited time could be devoted to these pages, errors and imperfections will doubtless appear to those more proficient in scientific learning and the art of book-making; but their usefulness need not be impaired on that account, if they aid those seeking practical information to correct false impressions, to remove uncertainties, and raise the standard of heating and ventilation to a place which they have failed to reach, but which their importance demand.

JOHN H. MILLS.

ACKNOWLEDGMENTS.

Having received many favors and kindnesses from others, the writer would show to friends of his early days and struggles that the talent acquired by their kindness has not, as sometimes, been buried in the sand of indifference or neglect; that if by much usury it has become five, he would fain return the interest to others who, like himself, begin life with only hope, ambition, a leaning to the sciences and mechanic arts.

To the following firms and individuals the author tenders these frank although late acknowledgments:—

The successors of Geo. W. Walker & Co., his first employers.

Walworth Manufacturing Co., of Boston, Mass.

H. B. Smith Co., of Westfield, Mass.

Providence Steam and Gas Pipe Co., of Providence, R. I.

To Engineers Charles W. Newton, Levi R. Greene, B. F. Sturtevant, Henry Williams, and others, who, realizing existing defects in the application of heat, and feeling the trammels of precedent and limited opportunity, gave freely from their store of mature experience to one who sought by practical and extended experiments to increase the common store of useful knowledge.

To John A. Whipple and Caleb Clark Walworth the writer would return his grateful thanks for their personal friendship and support, extending over a period of twenty years.

To Dr. J. B. Andrews, Superintendent of the Buffalo Insane Asylum, the writer is indebted for much personal kindness and assistance while remodeling the heating and ventilation of that Institution in 1886.

To those other readers who are living in the present rapid current of thought, invention and discovery, breasting each a wave thrown up by his own momentum, glad always to see some swimmer in the van, the thoughts, theories, and successes of a fellow-laborer may have their interest; and the writer, having cast his mite into the box of knowledge, trusts that it will not remain at the bottom without interest or benefit to those for whom it is intended.

INTRODUCTION.

WHILE considering the preface a sufficient explanation of the motives prompting the following pages, some further reference to the aim of the writer and the origin of the work seems desirable and due to the reader, who, having kindly given his attention and patronage, will be protected from surprises, while the author may claim the right to be judged by his own statements and intentions rather than by other standards liable to be set up for him, to which he lays no claim.

A mechanic by trade, an amateur in the sciences, without the advantages of a liberal education, and constrained to daily labor, may not hope to add to his other records originality of theme, the grace and polish of the scholar, or the accuracy of the mathematician.

It is not, therefore, in a literary line or as a teacher of the sciences that the author expects approval, and his effort to show the relation and value of the sciences to the construction and operation of heating apparatus may be all too crude to satisfy even his friends.

But as these same friends have so often and kindly urged him to put his studies, experiments, and constructions in some connected and readable form, they must bear their part in the responsibility, if the result is not a credit either to their partiality, or the author's desire to make a fitting return for it. A few of these letters are introduced showing the inferences stated, also that the interest and expression of it were not confined to one occupation or locality.

It was not the author's original intention to attempt a large or elaborate treatise, even in the lines and subjects most familiar to him, or to essay an exhaustive compilation of what others had done, said, or written, except in so far as would bring under review in some regular and consecutive order the several subjects and sciences embraced in any intelligent study of Heat and Heating Apparatus.

The first estimates of the size of the book and time required, for a review of the main conditions, has been largely exceeded, and what was at first intended for one volume has become two, with a probability of a third, or hand-book, into which may be bound all the *key pages*, *tables*, and *diagrams*, for facility of reference, outside of any study of the sciences involved.

That the author has also been his own publisher, should explain the time required and something of the financial and other burdens assumed, being compelled to desist from contracts and other remunerative labor for the past two years, while much time had previously been devoted to collecting and arranging the record of his own and the reported work of other Engineers.

However much may be understood by engineers or specialists in these branches, there yet appears a dearth of practical information among other classes as to the main and fundamental principles governing the production and application of heat, to say nothing of the use of materials and labor that may be saved or wasted by imperfect plans and faulty execution.

As evidence of this, one has only to ask a simple question of different individuals connected with heating and ventilating operations, to learn that scarcely any two of them agree in theory or practice, or recognize any law or principle other than those which fit their personal operations or the machines they have for sale.

It is not assumed that every inventor, workman, or steam-fitter should be the graduate of some technical school or other institution of learning; but the writer would impress upon all his readers, that such is the relation of sciences and practical knowledge to every operation connected with the heating and ventilation of buildings, that no one can wonder at failure, or expect success without a knowledge of principles, as well as practical construction and operation.

While addressing himself to the Mechanic, the Inventor, and the Manufacturer, and endeavoring to make his work and conclusions clear from the standpoint of their practical experience, he trusts that his handling of the sciences will not be below the notice and requirements of Engineers, Architects, and Professional men, and that the student in the higher branches of learning may find here the union of *theory* and *practice*, without which no desirable results have or can be obtained.

Although there may be nothing really new in principles, and nearly every possible application of them has had some example, still, seeing how little of the forces and elements available for man's advancement has been exhausted, and that a new use or better application of known agents is claimed as Invention, and credited as Discovery, the writer, having the courage of his convictions, will try to show how "*two blades of grass may be made to grow where but one grew before.*"

The inquiry starts where the writer's study and experiments began, but does not stop with them, since no one man, be he ever so energetic and industrious, could, in the few years available for this class of work, compass both the theoretical and practical bearings of the many trades and sciences involved. It thus happens that the author's original matter forms but the smaller part of the total text, the rest being made up from the words and work of different engineers and writers who, with better preparation and ability, have contributed to this library of special information. Although the works and writings of others have been freely consulted and quoted from, it has been the intention to "render unto Cæsar" that which was his, although it has been almost impossible to mention every source of information so received. A full list of books and papers consulted will be found at the end of the first volume.

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CHAPTER I

HEAT—ITS NATURE AND SOURCE.

PART FIRST.

HEAT, like all other physical agents, is known and measured only by its effects on matter. The principal sources of heat are:—

The Sun, which is the greatest source of heat, as well as light, to the earth. The *solid*, *liquid*, and gaseous fuels, as combined in *Wood*, *Coal*, *Oil*, *and the Gases*.

As the sun is the great source of heat and light, so combustion is the great source of artificial heat and light. We need only at present remark that combustion, in the ordinary conception of the word, is the rapid chemical union that takes place between the oxygen of the air and certain elements contained in organic substances, as wood, peat, coal, and other varieties of fuel.

Mechanical Action. Every arrest of motion produces heat; thus, a small bar of iron may be heated by simply hammering it. Compression and percussion are familiar methods of developing heat.

Chemical Action, or the action of atoms of dissimilar substances upon each other accompanied by complete change of properties. Examples of this are countless. One of the most familiar processes in which chemical action is exhibited, is the burning of fuel or illuminating substances.

Sensible and Latent Heat. When the heat received or lost by a body is attended by the sensation of warmth or coldness, the heat so lost or gained is called *sensible heat;* but, when a body receives heat or parts with it without causing sensations of warmth or coldness, the heat so lost or gained is called *concealed*, *hidden*, or *latent* heat.

The Essence of Heat is Motion. With a few exceptions the universal effect of heat on all matter is to expand it.

We say that bodies are heated and cooled, that one warms another near it; but we strictly mean only that they *expand* and *contract*, and that in expanding one body contracts the others, and in cont expands them. Hence, divested of everything not belonging t find the effects of heat a motion, or expansion, of matter comm from body to body. The motion of a mass implies the moti parts.

THE EFFECTS OF HEAT ARE:

Expansion. All solid bodies except clay are increased in volume, or bulk, by heat. Liquids when heated expand much more than solids; thus, water heated from 32° to 212° increases in volume one twenty-second part. The higher the temperature, the greater the rate that liquids expand.

Aeriform bodies expand equally under a given increase of temperature. At 212° their volume is one third greater than at 32°.

Liquefaction. The first effect produced on solids by heat is expansion. If the heat be increased, they melt or become liquid, as is the case in the melting of ice, wax, or lead.

The melting point of a given solid is always fixed and constant, but it varies greatly with different solids.

Thus mercury is melted at 39°, ice at 32°, wax at 142°, lead at 612°, wrought iron at about 2,800°, and platinum at 3,280°. When a solid is converted into a liquid, heat is absorbed; when a liquid is converted into a solid, latent heat is given out.

Vaporization. Heat applied to a solid, first expands it, then melts, and finally converts it into a vapor.

When a solid or liquid is converted into a vapor, sensible heat is absorbed. In changing water of 177° into steam, 1,000 degrees or units of heat disappear. When the vapor is turned back to a liquid or solid, the latent heat is given out or becomes sensible.

Incandescence. Heat when imparted to bodies in a certain quantity will in many cases render them luminous.

If iron is heated to a certain degree, it becomes *red-hot*, which merely signifies that it emits a red light, and when white-hot, a white light. This luminous state is called incandescence. Coal at 750° is black; at 908°, incipient red; at 1,797°, full cherry red; at 2,951°, dazzling white; at 4,347°, intensely brilliant.

The atmosphere as the source of oxygen claims a brief mention here.

The Atmosphere. The earth and the sea are covered with a great but unknown thickness of elastic fluid called the atmosphere. Being gaseous, it consists of material particles not held together by the force of cohesion, but nevertheless made up of atoms capable of forming solids.

A hundred parts of pure air in a dry state contain *twenty-three parts by weight of oxygen* and *seventy-seven of nitrogen*. One hundred volumes of dry air contain 79.12 *volumes of nitrogen*, 20.80 *of oxygen*, .04 of *carbonic acid*, .04 of *carburetted hydrogen*, with traces of ammonia.

Let it be observed that the gases forming the atmosphere [illegible] chemically combined; they are mixed mechani[illegible] fr[illegible] ever part of the world, the proportion of oxyg[illegible] the same, and is scarcely influenced by se[illegible]

FUEL—GENERAL CONSIDERATIONS.

The word "fuel" is derived from the French *feu*, signifying fire, which is closely related to the Latin *focus*, a hearth or fireplace. The term embraces all those substances which are employed in the generation of heat, such as wood, coal, peat, oils, etc.

A difficulty in arriving at the right view is that the current language concerning heat implies the material hypothesis. It is so natural to regard heat as a thing, to ascribe a substantive existence to that which is the subject of a name, that it will be necessary to guard against this misleading tendency. The reader should strive to think of heat, not as an abstract thing, but simply as a contagious or communicable motion of atoms.

An abundance of fuel is the basis of national prosperity, not only ministering to the useful arts, but enabling the occupants of every house to create an artificial climate suited to their wants.

The controlling agency of fuel in the development of body and mind and in the preservation of health has long been known; the unequal distribution of solar heat over the earth is regarded as the cause of marked difference in national character.

In Yorkshire and other parts of England where fuel is abundant, the people are generally well grown, healthy, and intelligent; their average height is said to exceed that in other parts of England where fuel is scarce. The Norwegians are generally well lodged, each house being furnished with glass windows, and an iron *Ka Kle*, or stove; and on this account they are a better-grown race than the Northwestern Highlanders, who procure their fuel with difficulty, and consume it in a rude and unthrifty manner.

In France, where fuel is scarce, the average height of a man does not exceed five feet, four inches; in the Netherlands, where fuel is more abundant, the average height is *five feet, six and one-half inches;* and in England, where fuel is cheap and abundant, the average height is upwards of *five feet, nine inches;* while in Sweden, where wood is as abundant as our coal, the peasants are tall, vigorous men, notwithstanding their uncleanly habits and the rigor of the climate.

It has been remarked that the Frenchman is never at home except when he is abroad,—a witty paradox, which, nevertheless, conveys much truth. His language is even destitute of a name for the place we call home—a name dearer than any other to the American heart. Who can d[illegible] the scarcity, and consequent high price of fuel, has had a po[illegible]ce in forming the customs and character of this nation, by t[illegible] the theatre and coffee-house those attractions which, o[illegible]her countries where fuel is abundant and cheap, [illegible]—the family fireside?

Fuel in the United States. It is hardly necessary to reiterate the well-understood and indisputable fact that an abundant supply of wood and coal, easily procured, has contributed more than any other resource to the rapid growth and prosperity of the United States. In no country has nature been more lavish in the distribution of her bounty, and nowhere have her choicest gifts been more wantonly and recklessly squandered. In many towns in the Eastern States, where fifty years ago wood was considered a nuisance, which every proprietor of land was trying to get rid of, it is now valued at $6 or $8 a cord.

The high price which coal and wood have commanded for several years has compelled all classes to fully appreciate the importance of the subject. Our public journals are agitating the question, and papers have been started devoted exclusively to the subject of fuel. Inventive genius and mechanical skill are hard at work endeavoring to devise some means by which the "black mud" of our swamps and bogs, and waste from the mines, may be made serviceable as a substitute for wood and coal.

The demand is still rapidly increasing. On account of the high price of labor and cost of transportation, supplies of fuel from our rich and inexhaustible coal fields can be available to many localities only at exorbitant prices; hence our forests are as yet a source of supply to a very large portion of the country. The rapid destruction of these cannot have escaped the attention of the most casual observer; while the entire lack of care for their preservation or effort for their restoration must awaken in every thoughtful mind a solicitude for the future.

To enter into an investigation of the many unhappy and disastrous results which will inevitably flow from this wholesale destruction of our forests would require a volume much larger than this, yet we cannot refrain from enumerating enough of these to demonstrate to the reader that our forest trees possess a value far beyond our ordinary estimation or conception.

Were we not emphatically a utilitarian people, the magnificent beauty of our forests would alone be a sufficient argument for their preservation. How much more pleasant to the eye is a hillside with its graceful trees, draped in foliage of the richest verdure, than a barren summit, destitute of nature's own protection! Who would exchange the tree-clad hills of New Hampshire or the evergreen mountains of Vermont for the sterile wastes of Nantucket or the monotonous flats of New Jersey? The unrivaled autumnal beauty of our forests is ever gazed upon by the old and the young with unwearied delight, and calls forth expressions of enthusiastic admiration from the European traveler.

The brilliant orange hues of the sugar maple, the gold and green of the elm, the modest yellows and unassuming buffs of th ebirch, the bright yellows and deep scarlets of the oak, the rich browns of the bass wood, and darker hues of the ash, the unfading green of the firs, pines, and other evergreens,—all these intermingled and blended with the richest tints of purple, crimson, and gold, in numberless forms, and shades ever changing to the eye of the traveler, like nature's grand kaleidoscope, present a sight which in gorgeous beauty outrivals our highest conception of imperial magnificence.

It is stated that, when the extensive pine forests in the neighborhood of Ravenna were cut down, the inhabitants began to suffer; afterwards the woods were allowed to grow, and the city is now free from the enervating influence of the sirocco, and its old climate restored. When English iron was excluded from Italy by the influence of Napoleon I., the furnaces of the valleys of Bergamo were worked to their utmost capacity. As the ordinary supply of charcoal was not sufficient to feed them, the young as well as mature trees were felled, and the whole economy of the forests was deranged. At Piazza Torre there was such a wholesale destruction of the wood, and consequently such an increased severity of the climate, that maize no longer ripened.

After a prodigious effort, the forests were restored, and grain once more ripened in the fields of Piazza Torre.

In France, since the destruction of the forests of the Cevennes, which protected a large and rich tract of land near the mouth of the Rhone from northwest winds, the olive has retreated many leagues, while the orange is confined to a few sheltered points along the coast. In Belgium trees have been planted on the right bank of the Scheldt, where before there was no vegetation; the shelter thus afforded by these young forests has rendered fertile large tracts of land which were formerly barren wastes.

Forests Exercise a Powerful Influence on the Quantity of Rain and Dew. The aridity of Spain, occasioned by the absence of wood, not unfrequently renders the crops too wretched to pay for gathering. Many districts in France have suffered from the same cause, and trees are now being planted with a view to restoration. In parts of Scotland many miles square have been planted with trees, attended with happy results. During the French occupation of Egypt in 1798, at Cairo and Alexandria rain did not fall for sixteen months. Since, however, Mehemet Ali and Ibrahim Pacha completed their vast plantations (the former alone having planted more than twenty millions of olive and fig trees, cotton-wood, orange, etc.), there falls a frequent and liberal supply of rain.

Forests Act as Copious Reservoirs for Retaining the Water After Rain Has Fallen. The foliage of trees retains a large quantity of water, thus preventing a rapid and destructive rise of streams. Water is also held by the accumulation of dead leaves, which tends to check the formation of dangerous torrents, and prevents sudden failures of streams in mountainous districts. Forests, by shielding the earth from the rays of the sun, greatly retard evaporation from the soil; consequently we are saved from severe droughts in summer.

In view of these important facts, shall we learn no lessons of economy, prudence, and wisdom? England and other nations have sinned in this particular, and now are reaping the bitter fruits of their reckless extravagance.

Shall we suffer this incalculable wealth of vegetable life to be ruthlessly squandered by a mad cupidity, which in the end will surely overreach itself? On the continent of Europe the management of forest trees receives the greatest attention, and is systematically conducted, and the formation of forests by sowing seed is now generally practiced. May not our forests be thinned and husbanded, instead of being utterly destroyed? May not the cold soil of our Northern States be rendered doubly productive under their grateful shelter and protection? And the flow of our streams be kept constant for manufacturing purposes? And may not the preservation of our forests be in some degree instrumental in securing to our population that vigor, both of body and mind, which characterized our ancestors a few generations ago?

The subject of preserving the magnificent forests of Michigan has engaged the attention of the Legislature of that State. Its forest wealth, once greater than that of any other State, is tributary to so many markets that it is rapidly disappearing. Such vast tracts were stripped that climatic changes, injurious to vegetation, have been induced.

Crops have been deteriorating for several years, and it is now believed that this is owing to the despoliation of the woodlands. The increasing severity of the winters, by which forest trees have been killed, and the diminution of fertilizing rains have been attributed to this cause.

From the clearing of so large a section of timbered lands the cultivated districts have been exposed to the ravages of blighting winds. The loss to the wheat crop in one winter from this cause is estimated at $5,000,000. It is proposed to mitigate the evil by exempting forests from taxation and by other effective measures.

Wood. Taking the briefest possible glance at the several fuels available for the generation of heat, we start with wood, which is the most common and widely diffused of all the substances used for producing heat. .

It consists chiefly of woody fibre, sap, and water. Wood-fibre, which forms the principal bulk of plants, is composed of carbon, oxygen, and hydrogen. The sap of the pine and other cone-bearing trees contains *resin*, that of oak *tannin*, and that of maple, *sugar*. The amount of water in wood varies greatly with the kind of tree and season of the year when it is cut; a portion of the water evaporates, yet a large proportion remains; for air-dried wood, as commonly used, contains about thirty per cent of water. As water is not combustible, its presence in wood diminishes its value as fuel; the water must be drawn off at the expense of the heat; the water can be expelled only by converting it into steam, and the process requires a large expenditure of heat. If one hundred pounds of wood contain thirty pounds of water, there remain but seventy pounds of combustible matter. It will require one pound of wood to raise thirty pounds of water to the boiling point, and six pounds more of wood to convert it into steam, making one tenth of the combustible material of the wood.

Value of Different Kinds of Wood for Heating Purposes. Some varieties of wood are soft and light; others, having their fibres more closely packed, are hard and heavy; soft woods kindle easily, are more active in combustion during its first stage, while harder varieties are more active during later stages; soft woods burn with a larger volume of flame, while hard woods give little flame, and produce a large amount of coals. The common opinion, that soft wood, taken pound for pound, evolves less heat than hard wood, is erroneous. It is sooner consumed, because it is more porous and admits the air more freely; but it gives out an intense heat while it lasts, and is therefore well adapted for those purposes where a rapid and powerful heating effect is required, as for the generation of steam.

Some important experiments on the relative heating qualities of the different American woods, also coal and coke, were made by Marcus Bull.

Table No. 1 shows the results which he obtained, also the analysis of composition, the water expelled at different temperatures, and the weight of air required for the proper combustion of most of the fuels employed,—such as wood, hard and soft coal, coke, peat, and charcoal, —thus forming an instructive and valuable reference for the student and engineer.

TABLE No. 1.

THE RESULTS OF EXPERIMENTS ON SOME OF THE MORE COMMON VARIETIES OF FUEL—WOOD, CHARCOAL, COAL, AND COKE.

BY MARCUS BULL.

WEIGHT OF AIR REQUIRED FOR COMBUSTION OF FUELS.	LBS.
Anthracite Coal, . . .	12.13
Bituminous Coal, . . .	10.98
Coke, ...	11.28
Charcoal, ...	11.16
Peat, dry, ...	7.08
Wood, dry, ...	6.00

(Haswell, Pg. 671.)

	Specific Gravity of dry wood.	Avoirdupois pounds of dry wood in one cord.	Products of charcoal from 100 parts of dry wood by weight.	Specific Gravity of dry coal.	Pounds of dry coal in one bushel.	Pounds of charcoal from one cord dry wood.	Bushels of charcoal from one cord dry wood.	Time 10° of heat were maintained by the combustion of a pound of each article.	Heating value of specified quantity of each article. Shell-bark hickory—100.
								H. M.	Cords.
1. Shell-bark Hickory, . . .	1.000	4469	26.22	0.625	32.89	1172	36	6–40	100
2. White Oak, ...	0.855	3821	21.62	0.401	21.10	826	39	6–20	81
3. White Beech, ...	0.724	3236	19.62	0.518	27.26	635	23	6–00	65
4. Black Birch, ...	0.697	3115	19.40	0.428	22.52	604	27	6–00	63
5. Hard Maple, ...	0.644	2878	21.43	0.431	22.68	617	27	6–10	60
6. Soft Maple, ...	0.597	2668	20.68	0.370	19.47	551	28	6–00	54
7. Yellow Pine, ...	0.551	2463	23.75	0.333	17.52	585	33	6–30	54
8. White Birch, ...	0.530	2369	19.00	0.364	19.15	450	24	6–00	48
9. Hard Pine, ...	0.426	1904	26.76	0.298	15.68	510	33	6–40	43
10. Chestnut, ...	0.522	2333	25.29	0.379	19.94	590	30	6–40	52
									Tons.
11. Lehigh Coal, ...				1.494	78.61	. .	. .	13–10	99
12. Susquehanna Coal, ...				1.373	72.25	. .	. .	13–10	99
									100 bush.
13. Cannel Coal, ...				1.240	65.25	. .	. .	10–30	230
14. Scotch Coal, ...				1.140	59.99	. .	. .	9–30	191
15. Oak Charcoal, ...				0.401	21.10	. .	. .	15–00	106
16. Pine Charcoal, ...				0.285	15.00	. .	. .	15–00	75
17. Coke, ...				0.557	29.31	. .	. .	12–50	126

(Dimond, Pg. 46)

By M. Violette.	Water Expelled from 100 Parts Wood.				Analysis of Composition, by Eugene Chevandier.					
Temperature.	Oak.	Ash.	Elm.	Wal't		Per Ct. Carbon.	Per Ct. Hyd.	Per Ct. Oxyg.	Per Ct. Nitro.	Per Ct. Ash.
					Oak, . .	49.64	5.92	41.16	1.29	1.97
257° Fahr., . . .	15.26	14.78	15.32	15.55	Beech, .	49.36	6.01	42.69	0.91	1.00
302° " . . .	17.93	16.19	17.02	17.43	Birch, .	50.20	6.20	41.62	1.15	0.81
347° " . . .	32.13	21.22	36.94	21.00	Poplar, .	49.37	6.21	41.60	0.96	1.86
392° " . . .	35.80	27.51	33.38	41.77	Willow,	49.96	5.96	39.56	0.96	3.37
437° " . . .	44.31	33.38	40.56	36.56	Average,	49.70	6.06	41.30	[illegible]	[illegible]

(Barr, Pg. 37.)

CHAPTER II

MINERAL COAL AND ITS PRODUCTION.

MINERAL COAL. This variety of fuel consists of carbon, together with bituminous substances composed of carbon and hydrogen. There is always present more or less of earthy impurities, as silica, alumina, oxide of iron, sulphur, etc. Coal gives unmistakable evidence of having been derived from an ancient vegetation long buried in the ground, and subjected to a slow and incomplete combustion. All vegetable tissues consist largely of carbon, hydrogen, and oxygen. Dry vegetable matter contains about 49 per cent of carbon, 6.3 of hydrogen, 44.6 of oxygen.

If we abstract from the wood the greater part of its oxygen, and submit the remaining constituents to a pressure sufficient to render them very compact, the product formed will resemble in every respect the softer and more inflammable varieties of coal. When large quantities of vegetable matter are buried in the earth, with an almost entire exclusion of air, a similar result is obtained. Most of the oxygen, and a small portion of the hydrogen of vegetable tissues, escapes, and a residue rich in carbon and hydrogen is left. These hydrocarbons, as they are called, variously affected by heat and pressure, furnish all the different varieties of coal.

"Coal has all the characteristics which entitle it to be considered the best natural source of motive power. It is like a spring wound up during geological ages for us to let down. Coal contains light and heat bottled up in the earth, as Stevenson said, for tens of thousands of years, and now again brought forth and made to work for human purposes. The amount of power contained in a pound of coal is almost incredible. In burning a single pound of coal, there is force developed equivalent to that of eleven million four hundred and twenty-two thousand pounds falling one foot; and the actual available power obtained from each pound of coal, in a good steam engine, is that of one million pounds falling through one foot. That is to say, there is spring enough in coal to raise a million times its own weight a foot high. In coal we [illegible]y find, as the partner of Watt said, 'what all the world [illegible].'"

*"**The total production of coal in the world** is put at 420,000,000 tons, of which Great Britain does 160,000,000, the United States 120,000,000, and Germany 75,000,000 tons. The production in the United States is divided between 31 States and Territories, the largest of course being Pennsylvania, which last year gave us 34,000,000 of anthracite and 30,000,000 of bituminous. In money value the output in the United States is safely $500,000,000 in the markets where it is used. This is greater than the value of the gold, silver, cotton, and petroleum produced in our country.

It is only in a few weeks that the semi-centennial of ocean steam navigation has been held. In 1838 the steamer "Sirius," of 700 tons register, 1,340 tons burden, arrived at New York. It took her 14 days, and she used 600 tons to make the voyage. Now we have the "Etruria," with a burden of 7,718 tons and using 2,000 tons, and making the trip in 6 days. It is stated that the exports from Great Britain for the use of foreign steamers is 7,000,000 tons annually. At New York alone the ocean steamers take on 1,250,000 tons; while, if we took into consideration the vessels of the rivers, the inland lakes, and the coast, we might make the sum total 10,000,000 tons. The railway companies of the United States furnish the next largest consumer. It is stated that 22,000,000 tons are used annually by the railways of the country.

What is a million of tons? Did you ever stop to consider what is meant by that phrase? Just fancy, if you can grasp the idea, that last year we mined 120,000,000 tons in the United States alone. This is a large tonnage, and you hardly know what to make of it. One million of tons would represent a string of gondola cars, 25 tons each, 40 in a train, and 1,000 such trains. They would stretch across this continent running only a mile apart. It is, no doubt, difficult to grasp the idea of 120 times this quantity. If you can do so, then you have some idea of the extent and magnitude of our fuel consumption in the United States. What is it worth? We can best answer this question by giving the value at the initial point of production, as the price varies with the distance from the mines.

Taking the 34,000,000 tons of anthracite coal produced last year, at a value of $2.50 per ton, would be a fair basis, and the 85,000,000 of bituminous at $1.25 per ton.

It takes an army of 273,000 persons merely to produce and prepare this commodity for the market, to say nothing of those who are engaged in the traffic after it has been produced,—along railways, at shipping points, in the yards, etc.

It is safe to say that 90 per cent of the selling price at wholesale is made up of the wages paid.

* *The Engineer*, Aug. 11, 1888.

The bituminous coal of this country, which forms so large a proportion of the total, is produced, carried, and sold for a less price than in any other country in the world. From Western Pennsylvania, Ohio, Illinois, and Indiana there is a production that will foot up the total of 35,000,000 tons.

Pennsylvania, in one county only, produces 5,090,000 tons annually. Ohio contains plenty of good coal.

Illinois is blessed with plenty of good coal that is cheaply mined, transported, and sold. Chicago gets coal at $2 per ton, while St. Louis manufacturers obtain their supply at the rate of $1.50 per ton. Manufacturers about Pittsburg can buy their coal for $1.25 per ton delivered at their works, and we know of recent contracts at Buffalo at $1.60 per ton. Some remarks in regard to the varieties of anthracite might be in order. Lackawanna is one of the oldest and best known. The Pittson, mined by the Pennsylvania Coal Company, is about the next oldest, having been worked consecutively since 1851. Lehigh is not very largely used outside the State of Pennsylvania and the Atlantic seaports, although its value in comparison with the free burning coals of the northern fields would warrant a larger sale and consumption if it could be had in quantity.

A few facts with regard to the amount consumed in the various cities of the Union might be in order. In New York, including Brooklyn and Jersey City, we may safely put the consumption for all purposes at 8,000,000 tons per annum.

Chicago will use 4,000,000 tons, while Cleveland will use 1,250,000 tons. These figures do not, of course, include anything arriving at the several points for redistribution, as it may be termed.

Varieties of Mineral Coal. The principal varieties are anthracite and bituminous. The former is the most condensed and the richest in carbon; some specimens contain 90 per cent of carbon. It is tough, very compact, and possesses a high lustre, in color varying from a jet black to a dark lead gray; its density and freedom from volatile matter make it an excellent conductor of heat, and thus prevent its ready ignition. When once thoroughly fired, it burns for a long time, emitting an intense concentrated heat.

The physical properties of coal include most of the general properties of matter.

It belongs to the non-metallic class of bodies, is a solid, varying in structure from a hard, crystalline, to a compact, earthy body bearing a close resemblance to wood.

An[illegible]ites do not fuse at all in the fire, while Bituminous sometimes fuse, [illegible] without decomposition. In specific gravity it varies from 1.55 t[illegible]

Anthracite coals are often divided into the Red-ash and the White-ash, according to the color of the earthy impurities which remain after the coal has been consumed. Anthracite has been employed in this country since 1820 for heating purposes, and during the last twenty years for culinary purposes, both in close stoves and in open grates.

It has high evaporative forces; but, from the intensity of the combustion, it causes the iron base of the grate and boiler to oxidize rapidly.

Bituminous Coal. This is a mechanical mixture of carbon and bitumen. Bitumen is the general name for certain compounds of carbon and hydrogen which result from the decomposition of vegetable substances. It resembles pitch or tar, and is highly inflammable. Its composition is: Carbon 75 to 80 per cent, hydrogen 5 to 6 per cent, nitrogen 1 to 2 per cent, oxygen 4 to 10 per cent, sulphur .04 to 3 per cent, ashes 3 to 10 per cent. Heat units 13,000 to 14,000 per pound.

Cannel coal is a dry and highly bituminous coal of close texture, and possessing a faint lustre. It is remarkable for the readiness with which it ignites, being kindled at once in the flame of a lamp, and continuing to burn with a highly luminous yellow flame without melting. This property renders it well adapted for illuminating purposes, and has given it the name of cannel, which is the pronunciation of the word candle in Lancashire, where the name was first applied. In Scotland farmers use it for candles. It is susceptible of receiving a fine polish, and is often made into boxes and other articles.

Coke. Coke is a brittle, porous solid, of a grayish black color. It is artificially prepared by a process called coking, which consists in expelling the volatile matter from the bituminous coal, and is usually carried on in ovens made of fire brick or stone. The charcoal is introduced at the top, and, being lighted, a little air is admitted by openings in front. When the coal ceases to evolve smoking vapors, the supply of air is cut off, and the oven allowed to cool for a day or two. A door in front is then opened, and the coke is raked out while still hot. Water is thrown upon it to prevent farther combustion. When coal of small size is used, water is sprinkled over it previous to firing, that the operation of coking may proceed more completely.

The quantity of coke obtained from a ton (two thousand pounds of coal) varies from a thousand to sixteen hundred pounds, so that the coal sustains a loss of from 20 to 50 per cent of its weight. At the same time it increases in bulk nearly one fourth. The coke absorbs moisture from the atmosphere, sometimes to the extent of 30 per cent.

It gives off no smoke in burning, and evolves a large amount of h[illegible] It is extensively used in smelting metallic ores in those localities [illegible] anthracite cannot be obtained.

It is also used in furnaces and fire-chambers of locomotives, because no means have as yet been devised for effecting such a complete combustion of those hydrocarbons which are expelled in the process of coking, as to avoid the escape of large volumes of smoke. Could this be accomplished, we should save, not only the 20 to 50 per cent of valuable heat-giving constituents of coal, but also the expense of coking.

Connelsville Coal. From this coal the celebrated foundry coke is made. The coke is very hard, occurs in long pieces not unlike stove wood, and is of a steel-gray color, having a bright metallic lustre. It is used largely in the Middle and Western States for the smelting of iron in cupola furnaces, and is a most excellent fuel for the purpose. The same as Lehigh anthracite coal, it yields an intense heat, burns free under a strong blast, and will support a considerable weight of iron above it in the cupola without crushing.

Charcoal. This variety of fuel is a black, brittle, inodorous, lusterless solid. It is produced by depriving vegetable substances of their volatile constituents.

This is effected by the agency of heat. The wood is piled so as to form a mound, and then covered with turf and soil in such a manner as to almost entirely exclude the admission of air, and thus prevent complete combustion.

A sufficient volume of air is admitted to keep up a slow combustion for several days, or, if the quantity is large, for several weeks. When the wood is thoroughly charred, the air is entirely excluded, and combustion ceases.

The charcoal produced retains the form of the wood, but is much reduced in size and weight, seldom amounting to more than three fourths the bulk of the wood, and one fourth of the weight. A cubic foot of charcoal from soft wood weighs only eight or nine pounds; from hard wood twelve to thirteen.

Charcoal, newly made, burns without flame, but it soon absorbs moisture from the air, which is condensed in its pores. When the charcoal is burned, a portion of the water is decomposed, and hydrogen is set free, which takes fire and burns in connection with the carbon, producing a small amount of flame. Charcoal ignites readily, and gives a large amount of heat.

At high temperatures charcoal has a powerful affinity for oxygen, and is of great service in reducing metals from their oxides in smelting furnaces. Charcoal has one advantage over wood, bituminous coals, and every kind of fuel containing hydrogen; namely, that the products of combustion are dry, whereas, if hydrogen is present in other fuels, water is always found in considerable quantities, every ounce of hydrogen producing nine ounces of water.

Peat as an Article of Fuel. The term "peat" is applied to the organic matter or vegetable soil of bays, swamps, beaver meadows, and salt marshes. It results from the decay of many generations of aquatic or marsh plants, as mosses, grasses, and a great variety of coarse shrubs, mingled with mineral substances derived from those plants, or blown and washed in from the surrounding lands.

How Peat Is Formed. In this country the production of peat from fallen leaves and decaying plants depends on the presence of sufficient water to saturate these vegetable substances and thus hinder the free access of air.

Saturation with water also has an effect to maintain the decaying matters at a low temperature, and by these two causes in combination the process of decomposition goes on very slowly. The solid products of such slow decay are compounds which themselves resist decay, and hence they gradually form accumulations, sometimes of great extent.

To that remarkable animal, the *beaver*, we owe many of our richest peat bogs. These creatures, from time immemorial, have built their dams across rivers, thus flooding the adjacent forests. In the rich leaf mould at the water's edge, and in the cool shade of the standing trees, has begun the growth of the sphagnums, sedges, and various purely aquatic plants. These, in their annual decay, have shortly filled the shallow borders of standing waters, and by slow encroachments, going on through many years, have occupied the deeper portions, aided by the trees, which, perishing, give their fallen trunks and branches toward carrying on the work.

Peat is generally less efficient in the production of heat than wood, though having an equal or greater proportion of carbon. The reason for this is found in the fact that it occupies a greater bulk for a given weight, a necessary result of its porosity. The best, or poorer qualities artificially condensed, may, on the other hand, equal or exceed the best kinds of wood in heating power, taken bulk for bulk. Another reason that renders some kinds of peat inferior to wood, in heating effect, is the great quantity of incombustible ash that it contains.

Peat Charcoal. The common and simple mode of carbonizing or charring ordinary peat is to arrange it in heaps, the same way that wood is piled for making charcoal; the sods or blocks must be regularly placed, and laid as compactly as possible. They should be about fifteen inches long by six broad and six thick. The heaps, built hemispher-ically, should be smaller in size than piles of wood usually are. In general, some five or six thousand large sods compose the heap.

The mass must be allowed to heat more than is necessary for w[illegible] and the process must be very carefully attended on account [illegible] extreme combustibility of the charcoal.

The quantity of charcoal obtained by this method is generally from 20 to 30 per cent of the weight of dry turf. For many industrial purposes the charcoal thus produced from peat in its natural state is too light, because, generally speaking, it is only with fuel of considerable density that the most intense heat is produced. It is therefore only with peat in a solidified state that we can expect to prepare a charcoal thoroughly adapted as a fuel for the more severe processes required in the arts. By coking this, however, a charcoal is produced of a density of 1.04 or upwards, which is superior to the best wood charcoal.

Peat in Europe. At the great exhibition of 1855, numerous specimens of peat and peat charcoal prepared by different patent processes were exhibited, which were remarkable for their density, and also for their cheapness.

In the city of Paris, peat moulded in small bricks, of sufficient density to sink in water, is supplied for domestic purposes from numerous sources. Peat as an article of fuel has, until recently, been used in this country only to a very limited extent; but in Europe it has been employed, both for domestic and manufacturing purposes, for several centuries. Dr. King, an Irish writer, in 1685 says of turf: "It is accounted a sweet fire; and, having very impolitically destroyed our wood, and not as yet found stone coal, except in a few places, we could hardly live without some bogs. When the coal is charred it serves to work iron, and even to make it in a bloomary, or iron work."

Peat Used for Generating Steam. Some experiments have been made in this country on the value of peat as a fuel for locomotive or stationary boilers. One was tried on the N. Y. Central R. R. Jan. 3, 1866. A locomotive with twenty-five empty freight cars attached, on a cold day with opposing winds, was propelled from Syracuse at the rate of sixteen miles an hour; the engineer reported that the peat gave as much heat as the wood, and burned with a beautiful fire.

Chemical Composition of Peat. The process of burning demonstrates that peat consists of two kinds of matter, one of which, the larger portion, is *organic*, or vegetable, in its composition, and is combustible; the other smaller portion is *inorganic*, or ash, and is indestructible by fire. Like that of the vegetation from which it originates, the organic part consists of carbon, hydrogen, oxygen, and nitrogen.

In the subjoined table are given the proportion of these elements, as found in several specimens of peat in various stages of ripeness: —

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
1. Peat, porous, light br[illegible]	50.86	5.80	42.57	0.77
2. " " red bro[illegible]	53.51	5.90	40.59	0.00
3. [illegible] heavy, brown [illegible]	56.43	5.32	38.38	0.00
[illegible] dark, red brown [illegible] omposed . .	59.47	6.52	31.51	2.51
[illegible] black, heavy, [illegible] . . .	59.71	5.27	32.07	2.50
[illegible] own, heavy, [illegible] . . .	62.54	6.81	29.24	1.41

Curiosities of Coal. "Does any one, except a practical chemist, stop to think of all the substances which we get from pit coal and the almost inconceivable variety of their uses? Everybody is familiar with those of them that are in daily use, such as gas, illuminating oils, coke, and paraffine, but of the greater part few persons know even their names; science advances so rapidly, and its nomenclature is so extensive and abstruse. It is no wonder that merchants and manufacturers take advantage of this ignorance to foist upon the public articles of food or drink, or for the toilet, that, if they are not always dangerous to the health, have not in them a particle of the substances which they profess to contain. Though pit coal has been known for some hundreds of years, the discovery of its numberless products is confined to the present century. Illuminating gas was unknown one hundred years ago. Petroleum has been in use only about forty years, and it is scarcely more than fifty since some one discovered that stone coal was inflammable.

Nearly all the other products derived from soft coal have been discovered and applied in the interests of science or of fraud within the last twenty-five years. The first thought with regard to coal is that it is made to give heat and warmth; the next that one of its principal uses is to illuminate. But there are obtained from it the means of producing over four hundred colors, or shades of color, among the chief of which are saffron, violet blue, and indigo.

There are also obtained a great variety of perfumes — cinnamon, bitter almonds, queen of the meadows, clove, wintergreen, anise, camphor, thymol (a new French odor), vaniline, and heliotropine, some of which are used in flavoring; and various substances familiar or unfamiliar, such as tar, rosin, asphaltum, lubricating oils, varnish, and the bitter taste of beer. By means of some of these we can have wine without the juice of the grape, beer without malt, preserves without either fruit or sugar, perfumes without flowers, and coloring matters without the vegetable or animal substances from which they have hitherto been chiefly derived.

What is to be the end of all this? Are our coal beds not only to warm and illuminate, but to feed and quench the thirst of posterity? We know that they are the luxuriant vegetation of primal epochs, stored and compressed in a way that has made them highly convenient for transport and daily use.

They are nature's savings, laid up for a rainy day for her children; and it is probable that, because they are composed of the trees, the foliage, and the plants, the roots, the fruits, the flowers of the ancient world, they now so largely supply the place of our forests, plains, fields, and gardens."

Waste of Coal. This question may be considered under two heads—the first is waste in procuring; the second is waste in burning. Waste in procuring is partly inevitable, and partly preventable. Every blow of the pick reduces some of the coal to comparative powder, and the amount of waste from this source will vary with the quality of the coal as to tenderness, and with the character of the bed as to joints. Of the waste of coal in the collieries by the destructive practice above referred to, or by burning at the pit's mouth great heaps of small coal dust, it is not possible to present any precise information, but there is too much reason for apprehension that it greatly exceeds what the public may suppose, or the workers of collieries be willing to admit.

In common domestic fires it has been computed that seven eighths of the heat capable of being evolved from coal passes up the chimney unapplied, so far as mere warming is concerned. About one half the heat generated by the fire is supposed to be carried off with the products of combustion; and the remaining loss of heat is represented by the unconsumed combustible gases, and unburned particles of carbonaceous matter in the form of smoke. It is this which renders coal smoke so dark and offensive, and which is partly deposited as soot.

Relative Heating Value of Different Varieties of Coal. The qualities of American and foreign coals have been fully investigated by Prof. W. R. Johnson, and the results are presented in condensed form in Table No. 2, to which is added *the space which the several fuels occupy in cubic feet.* By inspecting this table we see that anthracite surpasses the foreign bituminous coals 20 per cent when compared by *equal weights*, and 26 per cent by *equal bulks*. In freedom from clinkerage, anthracite stands preëminent; in the rapid production of steam, when once in action, the Pennsylvania bituminous coals are most efficient.

Later investigations of the relative heating and evaporating power of hard and soft coal by Chief Engineer C. H. Baker, and by Chief Isherwood, U. S. N., also the Baltimore & Ohio R. R., show that, in extended use and under practical conditions, the advantage of anthracite over bituminous coals was reduced to *less than* 5 *per cent*, and that, for the *general uses of the Navy, the Board prefers the semi-bituminous coals.*

In respect to completeness of combustion the semi-bituminous coals generally excel the anthracites. Besides the wastefulness caused in the furnace by the greater formation of clinker with the latter coal, there is the greater labor necessary, and time lost in their removal.

The slack of anthracite is comparatively worthless on the grates of a boiler, whereas that of a free-burning coal, when burnt with proper appliances, is equally efficient in the formation of steam.

TABLE No. 2.

RELATIVE HEATING VALUES OF DIFFERENT VARIETIES OF COAL.

BY PROF. W. R. JOHNSON.

Space 2240 lbs. in cubic feet.

Anthracite Coal,	38–41 cubic feet.	
Bituminous Coal,	41–50	"
Coke, various kinds,	48–68	"
Charcoal,	104	"

(Haswell, Page 567.)

		Relative evaporative power of equal weights of coal.	Relative evaporative power of equal bulks of coal.	Relative freedom from a tendency to clinkerage.	Relative rapidity of action in evaporating water.	Facility of ignition.	Sums of relative values in the preceding columns.
Cumberland, Md. Free-Burning Bituminous.	Atkinson & Templeman's,	1000	1000	282	828	505	3615
	Easby's and "Coal in Stove,"	936	946	451	658	286	3277
	Easby & Smith's,	931	903	197	886	329	3246
	N. Y. and Md. Mining,	914	927	111	677	376	3005
	Neff's,	882	906	133	877	298	3096
	Averages,	932	936	235	785	359	3248
Anthracite of Pennsylvania.	Beaver Meadow,	923	982	1000	722	207	3834
	Forest Improvement,	940	955	741	790	150	3576
	Peach Mountain,	945	964	198	901	142	3150
	Lackawanna,	915	844	484	779	187	3209
	Lehigh,	835	872	555	792	153	3207
	Averages,	911	923	595	797	168	3395
Free-Burning Bituminous of Pennsylvania.	Queen's Run,	960	913	458	726	667	3724
	Blossburg,	908	911	176	996	596	3586
	Dauphin and Susquehanna,	873	835	171	766	602	3247
	Cambria County,	863	860	172	867	250	3012
	Lycoming Creek,	833	871	184	706	291	2885
	Averages,	887	878	232	892	481	3299
Foreign Bituminous.	Newcastle, Eng.,	809	776	191	827	595	3198
	Pictou, N. S.,	792	738	97	928	588	3143
	Sydney, N. S.,	747	669	276	764	424	2880
	Liverpool, Eng.,	733	663	323	857	581	3157
	Scotch,	649	625	107	847	521	2749
	Averages,	746	694	197	844	526	3027
General Scale of Relative Values from the Averages of Each Class.	Maryland Free-Burning,	1000	1000	395	880	682	3957
	Pennsylvania Anthracite,	977	986	1000	893	319	4175
	" Bituminous,	951	938	390	1000	914	4193
	Virginia Bituminous,	850	757	242	948	730	3527
	Foreign "	801	741	331	948	1000	3811
	Averages,	916	884	471	[illegible]		

(Dimond, Pg. 35.)

CHAPTER III

COMBUSTION A CHEMICAL PROCESS.

IT has already been stated that heat, for the generation of steam and for household purposes, is the result of chemical action, which takes place between oxygen and certain organic substances as wood, coal, peat, and other varieties of fuel. This process is called the *burning*, the *consuming*, or the *combustion* of fuel. Call it by what name we will, it is a *chemical* process, and therefore whatever pertains to its investigation lies strictly in the department of chemistry.

The subject involves a consideration of the nature and properties of the various kinds of coal and wood, and examines the action of their several constituents upon each other. It investigates a very difficult branch of chemistry — that of gaseous formations and their complex proportions, combinations, and equivalents. It involves the closest observation of the separate influence which each element of the atmosphere exerts on combustible bodies in the process of combustion. The burning of a single grain of bituminous coal includes a greater number of distinct natural phenomena and chemical results than almost any other process in the range of chemical science. And it is only by close scrutiny and patient investigation that we are able to unveil the mysteries of nature, discover her laws, and thus become familiar with her methods of operation, so as to secure the most important results.

Let not the practical man who reads these pages be alarmed at such terms as *oxygen*, *nitrogen*, *equivalent*, *combining number*, *etc.* Let him not suppose that he can dispense with a knowledge of these, if he would learn anything of the combustion of fuel. Without such knowledge he is at the mercy, and becomes too often the victim, of every speculative, smoke-burning quack, who neither understands nor appreciates the beautiful exactness and completeness of nature's processes.

It would be no more absurd for a child to try to read without knowing a single letter of the alphabet, than for a man to attempt to gain correct notions of combustion without first becoming familiar with the elements employed, and the laws which govern their action on each other. If the reader be not already familiar with these, let this and the following chapter be a brief introduction.

If the heat from fuel is due to chemical action, the first question to decide in entering into an investigation upon this subject is, *What is chemical action?* Under what circumstances does it occur? on what conditions does it depend? what laws, if any, control it? But it is chemical action between *oxygen* and certain *other elements*. The second question then to be considered is, *What is oxygen?* Where and how may it be obtained? what are its properties? what part does it play in combustion? Our third inquiry should be, *What are these other elements?* What are their qualities, and what office do they perform?

Chemical Action. Whatever occupies space, whatever affects our senses, is known as *matter*. A limited portion of matter is known as a *body*. Bodies are capable of undergoing three kinds of change — change of place, change of form, and change of nature. A piece of marble may be taken from the quarry, transported any distance, and wrought into a beautiful statue. This would be change of place and form, but the nature of the marble would still be unchanged.

Its crystalline structure would still be the same in the statue as in its native bed. These are *mechanical* changes.

If we should take the same piece of marble, and subject it to a high degree of heat, its *nature* would be changed; it would be separated into lime and carbonic acid, neither of which resembles marble.

Chemical action, therefore, is a name used to designate all those processes by which the nature of substances, in respect to form, color, taste, smell, and action upon other bodies, is changed, so that new substances unlike the old are formed. Thus wood exposed to the air for a long time decays; that is, its organic structure is broken up, and its elements converted into new substances; so iron is changed to iron rust; the juice of the grape is turned to wine; fuel in the stove wastes away.

Chemistry has shown that the solid crust of the globe, all the living beings on it, and the atmosphere which surrounds it, are composed of sixty-four or sixty-five elements.

An element, or simple body, is a substance which never has been derived from, nor resolved into, any other kind of matter. Thus silver and gold, oxygen and nitrogen, are called elements, because no force at our command has as yet been able to separate them into other elements.

A compound body is one that can be separated into two or more elements. Marble, for example, may be resolved by the application of heat into quick-lime, an invisible gas. Water may be separated into two colorless gases, hydrogen and oxygen. Hence these are called compound substances.

In these experiments we perceive the phenomena of chemical decomposition of compound bodies into their elements. The opposite exist, consisting in the chemical combination of two different bodies into one

Classes of Elements. Elements are of two kinds, *proximate* and *ultimate*. A compound body may be made up of compound bodies. The lime and the carbonic acid, of which the marble is composed, are themselves both compound, and hence these are only the *proximate* elements of the marble; but, after the lime has been resolved into calcium and oxygen, and the carbonic acid into carbon and oxygen, our analysis ceases. We cannot decompose the calcium, the carbon, the oxygen; hence we call these the *ultimate* elements of the marble. Of the sixty-six or sixty-seven ultimate elements found in nature, four are employed in the combustion of fuel — oxygen, hydrogen, nitrogen, and carbon. See diagrams 1 and 2, pages 71 and 74.

Chemical affinity, which is the attractive force exerted between the atoms of unlike substances at insensible distances, causing them to unite and form compounds possessing new and distinct properties. Of the cause or real nature of this and other forces, we possess no absolute knowledge. A stone thrown into the air falls to the ground. This movement is ascribed to the influence of gravitation — a force which is constant and universal in its action on all matter.

Cohesion is the attractive force which exists between similar particles at insensible distances, binding them together in one uniform mass, as a piece of wood, iron, or coal.

Chemical affinity is more restricted in its action, and is modified by various circumstances.

1st. It occurs only between the atoms of *dissimilar* substances. Two pieces of iron, or a piece of iron and one of copper, placed in contact, manifest no disposition to unite with each other; while *unlike* substances, as iron and sulphur, potassium and oxygen, may exhibit the most energetic kind of chemical affinity.

2d. In general, the *more unlike* any two substances are, the stronger is the chemical affinity between them. The metals, as a class, possessing many properties in common, show but a feeble tendency to unite with each other. Two alkalies, as soda and potash, will not enter into chemical union. Nitric acid may be mingled with sulphuric acid in any proportions, and no change of character is effected; the mixture is acid still. But if an acid is brought into contact with an alkali, as nitric acid with potash, they will combine, and produce nitrate of potash (salt petre), a neutral salt, possessing neither acid nor alkaline properties.

3d. Chemical affinity acts only on atoms removed from each other at insensible distances, thus requiring an *intimate mixture or incorporation* of the atoms to bring them within its range.

Thus tartaric acid and carbonate of soda will not unite while dry, but, if a po[illegible] of water be added to dissolve them both, and to leave the partic[illegible] move among each other, they will readily combine.

4th. Elements exhibit a far greater inclination to unite at the moment *when liberated* from some previous combination.

Substances in this condition are said to be in the *nascent* state (from the Latin *nasci*, to be born). Thus nitrogen and hydrogen will not, under ordinary circumstances, combine when mingled in the same vessel; but, when liberated from some other chemical combination, as during the putrefaction of animal matter, they unite to form ammonia.

The same compound is also produced in the furnace during the process of combustion, when hydrogen is allowed to escape and mingle with nitrogen, which is always present in great abundance.

5th. Every direct chemical union is attended by the *liberation* of heat and generally of light. The amount of heat evolved is in proportion to the rapidity of the chemical action. If iron is exposed to the air, oxygen will slowly unite with it, and produce the oxide of iron (iron rust). In this case heat is given off, but so gradually as to be imperceptible. While if a few drops of sulphuric acid are brought in contact with chlorate of potash, the chemical action is so rapid that sufficient heat is evolved to cause the whole mass to burst into flame.

6th. All compounds formed by the action of chemical affinity possess properties unlike those of their constituent elements. Chlorine, a suffocating gas, and sodium, a bright shining metal, unite, and give us common salt. The bluish white metal, mercury, and the yellow metalloid, sulphur, combine and form the bright red paint known as vermilion; and sulphur, uniting with black, solid carbon, produces a clear, colorless liquid, the bisulphide of carbon.

7th. The power exerted by chemical affinity is wonderful beyond description. An iron wire which will sustain a weight of several hundred pounds will readily yield if brought in contact with diluted sulphuric acid. A silver coin thrown into nitric acid will have its atoms torn asunder, and in a short time will be completely dissolved.

The force of chemical affinity between the atoms of a pound of hydrogen and eight pounds of oxygen is estimated to be equal to a mechanical force sufficient to raise forty-seven million pounds to the height of one foot.

8th. Chemical affinity unites substances only in definite proportions; and, since these are unalterable, the relative proportions of the constituent elements in any compound may always be expressed in numbers.

Water, for example, at the equator or at the poles, as rain, snow, ice, or vapor, is uniformly composed of eight parts, by weight, of oxygen and one part of hydrogen. The truth of this may be established both by analysis and by synthesis. When under favorable circumstances a current of electricity is passed through water, bubbles of gas will escape from each pole of the battery. On examination the bubbles from the

positive pole will prove to be pure oxygen, and those from the negative pole pure hydrogen.

And there will always be eight parts, by weight, of the former, to one of the latter. Again, water when artificially prepared by burning hydrogen in oxygen, requires just eight pounds, ounces, or grains of oxygen, for one pound, ounce, or grain of hydrogen. If nine grains of oxygen are taken, one grain will remain uncombined; or, if two grains of hydrogen be used, one grain will also be left free.

The union of these elements to form water will always take place in this proportion, and in no other. So lime is always found to be composed of eight parts of oxygen and twenty parts of calcium; common salt of thirty-five parts of chlorine and twenty-three of sodium; and thus with all chemical compounds.

Law of Multiple Proportions. Many of the elements have the power of combining with each other in more than one proportion. Thus by looking at the column of compounds in diagram 1, we notice that carbonic acid contains a double proportion of oxygen. But this is no contradiction to the statement that chemical affinity unites substances only in fixed proportions. For it will always be found that the larger proportion has a definite ratio to the smaller, being an exact multiple of it. If carbon or any other element unites with more than eight parts of oxygen, it will invariably unite with some multiple of it, as sixteen, twenty-four, etc. And the same principle applies to every chemical combination.

We find that hydrogen combines with other elements in the smallest proportion of any known substance; hence we take this as the standard with which to compare the combining quantity of any other element. This subject may perhaps be more clearly illustrated by the case of a merchant who wishes to count out a certain sum of money, taking half its value in silver and the other half in gold. He will be obliged to take fifty ounces of silver for every three ounces of gold.

In this case fifty ounces of silver would be equivalent to three ounces of gold. So in chemical compounds.

There is as much chemical energy in one grain of hydrogen as in eight grains of oxygen; that is, they neutralize and balance each other, so that, if we assume the equivalent or combining number of hydrogen to be one, that of oxygen will be eight; that of carbon six, since it requires six grains of this element to combine with one grain of hydrogen; that of nitrogen fourteen, for a like reason, and so on. And if we represent hydrogen by a circle of a given size, a circle eight times as large will represent oxygen. These placed side by side, as in diagram 1, illustrate the true composition of water. See page 71.

Combination by Volume. Of the four elements employed in the combustion of fuel, three are gases, as are also their compounds. It will be more convenient to deal with these by measure than by weight; and it will always be found that gaseous bodies combine with each in fixed and definite volumes, though these volumes may not have the same proportion to each other as the corresponding equivalents by weight. Thus the equivalent of oxygen is eight. We place eight grains of oxygen in a jar, which will contain exactly this quantity. The equivalent of hydrogen is one; but we find that the jar which held one equivalent, or eight grains of oxygen, will contain only half an equivalent, or one half grain of hydrogen. Therefore the equivalent volume of hydrogen is exactly double that of oxygen, while its equivalent weight is only one eighth that of oxygen.

Again, the equivalent of nitrogen is fourteen, and we shall find on trial that the jar will contain but half an equivalent of this gas; hence the equivalent volume of nitrogen is the same as that of hydrogen. The volume of two gases after combination is often less than the sum of their volumes in the separate state; or, in other words, two gases by their chemical union suffer a condensation.

Two measures of hydrogen and one of oxygen, for example, form only two measures of steam. All the diagrams in this treatise, with the exception of No. 1, will represent the relations and combinations of the different elements by *volume* instead of by *weight;* but hydrogen will still be the unit of measure. See diagram 2, pages 74 and 75.

Atoms. The laws of combining proportions which have thus far been explained, are the results of actual experiments.

For the remarkable phenomena displayed by that affinity which unites *chemical* substances in the manner we have seen, there *must* be a cause. There *must* be some cause which makes it impossible for elements to combine in any other than these proportions.

The chemist has numerous and powerful reasons for believing that all matter is composed of atoms; that is, of exceedingly minute, unchangeable particles. It has been objected that we cannot think of particles so small that, if possessing weight and figure, they may not be divided into still smaller quantities. Granting this, chemists nevertheless are compelled to assume that nature does ultimately limit the divisibility of matter. It is not insisted that *in theory* atoms are incapable of division, only that *practically* they are so. Every atom may perhaps consist of numerous smaller atoms, but *physically* it is considered indivisible and unchangeable. We may compare these ultimate atoms of matter to merchandise put up in certain forms. Thus many kinds of goods pass through a dealer's hands, sealed u[illegible] parcels, cans, or boxes,

which the merchant never opens. In practical commerce they are *indivisible*, though absolutely they are not so.

All matter is supposed to be composed of ultimate, indivisible, imperishable atoms, endowed with certain determinate properties, which we can neither alter nor destroy. The visible objects of nature are viewed as formed by the close arrangements of these atoms, as a massive edifice is built by placing together a great number of hewn stones or moulded bricks. Being solid and incapable of separation, these particles do not fuse or run into larger particles, as would be the case with two drops of a liquid metal, like mercury, placed in contact with each other; but, under the influence of various constraining forces, as cohesion, affinity, or electric power, they arrange themselves side by side in groups. Assuming that all matter is thus composed of associated atoms, the atomic theory, as it is called, teaches:—

That all atoms of the same element possess exactly the same weight.

That atoms of different elements may possess different weights.

That the number indicating the weight of an atom of an element is the same as the combining number, or equivalent, for that element.

RECAPITULATION.

An element, or simple body, is one that *cannot* be decomposed.

A compound body is one that *can* be decomposed.

The elements employed in the process of combustion are oxygen, hydrogen, nitrogen, and carbon.

The force which draws the elements together to form new substances is called chemical affinity.

Chemical affinity acts only on the atoms of dissimilar substances, and requires that these shall be at insensible distances from each other; hence the more perfect their intermixture, the more rapid will be the chemical action between them.

The more unlike two elements are, the stronger will be their affinity for each other.

Every chemical union is attended by the evolution of heat, and generally of light.

The quantity of heat evolved will depend on the intensity and rapidity of the chemical union.

Every chemical compound possesses properties unlike those of its constituent elements.

All elements, whether proximate or ultimate, enter into chemical union only in fixed and definite proportions.

The numbers expressing these proportions are called equivalents, or atomic weights. See diagrams 1 and 2, pages 71 and 74.

TABLE No. 3.

The Heat of Different Fuels and their Evaporative Power, with the Weight and Volume of Air Consumed.—Results of Experiment, Theory, and Practice.

No. for Reference.	AUTHORITIES. D. K. Clark, Morin & Tresca, Thos. Box, Haswell, S. A. Ford, Dr. G. E. Moore, Prof. W. R. Johnson, The Scientific American, William M. Barr, Favre & Silbermann.	No. of Cubic Feet to One Pound Atmospheric Pres. Temp. 62° F.	Air Consumed per lb. of Combustible. Lbs.	Air Consumed per lb. of Combustible. Cu. Ft. Density .0761.	Lbs. of Oxygen Consumed per lb. of Combustible.	Heat by the Perfect Combustion of 1 lb. of Fuel. Units.	Lbs. of Water Evaporated from and at 212° F. per lb. Fuel. Maximum E ÷ 966.	Lbs. of Water Evaporated from and at 212° F. per lb. Fuel. Average Practice
	COMBUSTIBLES. 1 lb.	A	B	C	D	E	F	G
	GASES.							
1	Hydrogen (forming steam)............	192.3	34.80	457	8.00	62,032	64.20	.....
2	Carbonic Oxide (forming carbonic acid)	13.6	2.48	33	0.57	4,325	4.48	.....
3	Marsh Gas (forming carb. acid & steam)	24.0	17.40	229	4.00	23,518	24.34	......
*4	Illuminating Gas { Mixture chiefly of hydrogen and marsh gas...... }	28.7	12.78	168	2.94	18,725	19.38	......
†5	Natural Gas (principally marsh gas)...	26.2	15.83	208	3.64	22,111	22.89	20.00
‡6	Water Gas...... { Carbonic oxide and hydrogen........ }	24.3	5.91	78	1.36	8,798	9.11	......
7	Gas from blast furnaces	Av. w'g't of 1 cu. ft.	.99	13	0.23	1,620	1.68	......
	LIQUIDS.							
8	Petroleum Oils....(73 per cent. carbon)	55	17.93	235	4.12	27,531	28.50	20.00
9	Amer. Petroleum. (85 " " ")	50	14.97	198	3.44	20,385	21.10	15.50
10	Alcohol ....(52 " " ")	49.6	9.12	128	2.10	12,339	12.77	......
11	Naphtha (density, .827)	51.7	......	......	......	13,208	13.69	......
12	Camphene (distilled from turpentine)..	......	14.14	186	3.25	20,200	20.91	......
	SOLIDS.							
13	Carbon (forming carbonic acid)........	......	11.60	152	2.66	14,500	15.00	......
14	Carbon { Burning to carbonic oxide (when the air is limited) }	......	5.80	76	1.33	4,452	4.61	.....
15	Coal, bituminous..(85 per cent. carbon)	80	11.29	148	2.60	14,400	14.91	8.94
16	Coal, anthracite....(90 " " ")	97	11.21	147	2.58	13,500	13.96	9.56
17	Coke ....(93 " " ")	45	10.90	143	2.50	13,550	14.02	10.92
18	Wood, kiln dried ..(50 " " ")	.....	6.10	80	1.40	7,792	8.07	5.00
19	Wood, 20 p.ct. moist.(40 " " ")	......	5.94	78	1.37	5,400	5.59	3.25
20	Charcoal, wood....(80 " " ")	......	7.90	104	1.85	10,800	11.18	.....
21	Peat, desicated... (59 " " ")	33	7.60	100	1.75	9,951	10.30	......
22	Peat, 20 p.ct. water (39 " " ")	39	6.32	83	1.45	7,200	7.45	4.26
23	Peat Charcoal.....(82 " " ")	......	9.25	122	2.13	9,000	9.32	......
24	Lignite ....(69 " " ")	80	8.85	116	2.03	11,678	12.10	......
25	Asphalt ....(79 " " ")	66	11.87	156	2.73	16,655	17.24	......
26	Straw, 16 p.ct. moist.(36 " " ")	......	4.26	56	0.98	5,196	5.56	2.30
27	[illegible]	127	4.35	57	1.00	4,032	4.17	......
28	Tan, kiln dried..........................	......	......	......	......	6,100	6.31	......
29	Tan, moist	42.5	......	......	......	4,284	4.44	3.69

* No. 4.—Illuminating Gas. Analysis of average composition, Thorpe's chemistry.

† No. 5.—By Analysis of Natural Gas from wells in the East Liberty District, near Pittsburg, Pa., by S. A. Ford, Chemist.

‡ No. 6.—Report on Water Gas (Strong Process) by Dr. Gideon E. Moore.

The amount of air supplied in practice is generally estimated as twice as great as that consumed (Col. C) for *solid fuels* and ordinary furnaces. For *gases* and *atomized liquids* the air supplied and consumed are, approximately, equivalent.

The volume of the products of combustion.—For *solid* and *liquid fuels* this is nearly the same as that of the air supplied (Col. C.) when expanded to the temperature of the escaping gases. For *gaseous fuel* the volume is that of the air and gas (Cols. C. and A.) at the temperature of the heated gas. (For Expansion, see Table 23.)

Heat lost by escaping gases.—This is equal (approx.) to the weight of air a[illegible] [illegible] by the specific heat of the gases (nearly the same as th[illegible] by the difference in temperature between the air admitted and the gases [illegible]

CHAPTER IV

ELEMENTS EMPLOYED IN COMBUSTION.

OXYGEN. Of the elementary substances with which modern chemistry has made us acquainted, oxygen is the most important and the most widely diffused. It constitutes, by weight, one fifth of the atmosphere, eight ninths of all the water on the globe, four fifths of all vegetable and three fourths of all animal substances, and nearly one half of the solid crust of the earth.

Pure oxygen may be easily obtained by selecting any of its compounds that will readily part with it, as, for example, the red oxide of mercury. In this compound the affinity between the oxygen and the mercury is so feeble that a very moderate degree of heat will destroy it, and the oxygen will be set free, and may be collected for examination, while the mercury will be found in small globules on the sides and bottom of the vessel.

Properties of Oxygen. Oxygen is a colorless gas, tasteless, and destitute of odor. It is about one tenth heavier than ordinary air (specific gravity 1.1057), and it forms about 23 per cent of the atmosphere. One hundred cubic inches of it weigh nearly thirty-four and one-fifth grains.

Oxygen is a neutral substance, having neither acid nor alkaline properties; but, though apparently weak and inert, it is endowed with the most remarkable properties.

Affinity for Other Elements. Oxygen possesses the widest range of affinity of any known substance. It combines with all the other elements, except fluorine, though its affinity for other substances varies widely according to circumstances. At ordinary temperatures it unites slowly with most metals. A piece of iron exposed to the oxygen of the air is attacked by it, and will be converted into the oxide of iron,—a process called oxidation,—but here the process is very gradual. With copper and many other metals it is still more so.

A stick of wood may remain for years exposed to the action of oxyg[illegible]t undergo but a very slight change; but when at a high te[illegible]gen seizes upon these substances with a terrible energy, ac[illegible]he generation of heat and light.

Hydrogen. This element is seldom found free in nature. The substance which contains it in the greatest abundance is water, of which it constitutes one ninth part by weight. It is also an essential constituent of the class of bodies termed *acids*.

In the mineral kingdom it is not very abundant, but it enters largely into the composition of many kinds of wood, and is always present, in greater or less abundance, in the different varieties of mineral coal.

How Obtained. Hydrogen, for purposes of experiment, is usually obtained by the decomposition of water. If strips of zinc are thrown into a jar containing water, a portion of the water is decomposed; the oxygen seizes upon the zinc and converts it into oxide of zinc, and the hydrogen is set free. Very soon, however, the zinc becomes coated with the oxide, and the operation ceases. But if sulphuric acid is added to dissolve the oxide, so as to present fresh surfaces of zinc to the action of the water, a constant supply of hydrogen may be obtained.

Properties of Hydrogen. Hydrogen is an invisible and, when pure, tasteless and odorless gas. It is the lightest of all known substances, being one sixteenth as heavy as oxygen and less than one fourteenth as heavy as air. One hundred cubic inches of it weigh only two grains. Hydrogen is highly inflammable, but will not support combustion.

Nitrogen is very extensively diffused throughout nature.

It forms about four fifths of the atmosphere, enters largely into the vegetable and animal kingdom, and is found in small quantities in some varieties of coal.

How Obtained. Nitrogen may be obtained by withdrawing the oxygen from a portion of the air. If a bit of phosphorus, placed in a cup and floated in a shallow dish partly filled with water, be set on fire, and a jar be placed over it, the phosphorus will take the oxygen from the air within the jar, forming phosphoric acid, which the water rapidly absorbs, leaving the nitrogen free.

Properties of Nitrogen. The gas, like oxygen and hydrogen, is invisible, tasteless, and odorless, but unlike them it is noted for its inertness.

It combines directly with no other element, and is therefore neither combustible nor a supporter of combustion.

A lighted taper introduced into a jar of this gas is immediately extinguished, nor will the gas itself take fire, as is the case with hydrogen, when it comes in contact with the atmospheric air. It is a little lighter than common air; if a given volume of air weighs one thousand grains, the same volume of nitrogen will weigh nine hundred and seventy-one grains. Its chief use in the atmosphere is to dilute the oxygen, and subdue the terrible energy of this wonderful and awe-inspiring element to an innumerable variety of useful purposes.

Carbon. This element, which forms the solid basis of most fuel, is among the most abundant and important of the elementary substances. It exists in nature under a variety of conditions. The diamond is carbon in its purest state, as may be proved by burning it with oxygen, when pure carbonic acid *only* is produced.

Charcoal and coke are well known forms of carbon. The former is obtained from wood; the latter from coal.

Properties of Carbon. Carbon at ordinary temperature has little or no affinity for other elements, and is consequently one of the most unchangeable of all known substances.

Grains of wheat charred at Herculaneum nearly two thousand years ago retain their form. At high temperature, however, carbon surpasses all other elements in its affinity for oxygen, and upon this property depends the most important part which it plays in the process of combustion of fuel.

Phosphorus and Sulphur. There are two other elementary substances which claim a brief notice, as we shall have occasion to refer to certain properties possessed by them.

These are phosphorus and sulphur. The former is a soft, colorless, semi-transparent, waxy solid, highly inflammable, bursting into a brilliant flame at a low temperature, and burning with great violence. If a small piece of phosphorus is placed in a small metallic cup, and lowered into a jar of oxygen, no rapid chemical action will follow; but, if the phosphorus be touched with a piece of heated wire, it will instantly kindle and burn with great intensity, giving out a light too brilliant to be endured by the eye. By reason of its inflammability it is kept under water; if exposed to the air it slowly oxidizes. Its chief use is for the manufacture of friction matches. For this purpose it is mingled with glue and other substances, as otherwise it would take fire with the least friction, or even by exposure to the rays of the sun.

Sulphur. This is found in great abundance in volcanic regions, in coal, and in some species of plants. It is a light solid, brittle, and, like phosphorus, very inflammable, taking fire at a low temperature. It burns with a beautiful flame, and forms sulphurous acid, a gas possessing a pungent, suffocating odor, which may readily be recognized on lighting friction matches, for the manufacture of which, like phosphorus, it is extensively employed.

Compounds of Oxygen, Hydrogen, Nitrogen, and Carbon. These four elements enter into combination with each other, and give rise to a large class of compounds, some [illegible] prominent part in the process of combustion. These [illegible] hydrogen and bicarburetted hydrogen. The f[illegible] *carburetted hydrogen, methane*, or *marsh gas*, [illegible]

Nature of These Gases.—Carburetted hydrogen is composed of one equivalent of carbon and two of hydrogen (by weight, six parts of carbon and two of hydrogen). This is a colorless, odorless, tasteless, inflammable gas; it burns with a bright, yellowish flame, and when mixed with oxygen and common air it becomes explosive. A given volume of this gas weighs a little more than half the same volume of common air (common air 1000, carburetted hydrogen 553 nearly).

Bicarburetted hydrogen is composed by weight of twelve parts of carbon and two of hydrogen. This is a colorless, tasteless gas, possessing a marked odor; is highly inflammable, burning with a bright and intensely luminous flame. It forms the better part of our illuminating gas. Like carburetted hydrogen, it is explosive when mixed with common air. Its specific gravity is a little less than that of common air (common air 1000, bicarburetted hydrogen 985). These compounds will receive attention as we enter upon an explanation of the chemical changes which take place during the process of combustion.

RECAPITULATION.

Oxygen is an invisible gas, possessing a powerful affinity for certain elements found in all combustible substances.

Heat is required to bring this affinity into rapid action.

The higher the temperature the more intense will be the action, and consequently the greater will be the amount of heat evolved in a given time.

Hydrogen is an invisible gas, an element in most varieties of fuel, combining rapidly with oxygen only at a high temperature, evolving an intense heat and producing water in the form of invisible vapor.

Nitrogen is also an invisible gas, possessing only negative properties. It combines directly with no other substance, and hence cannot be regarded as a heat-giving element in combustion.

Carbon is a solid, the chief constituent of all kinds of fuel, and when at a high temperature surpasses all other elements in its affinity for oxygen.

Phosphorus and *sulphur* are highly inflammable solids, entering into chemical union with oxygen at a lower temperature than most other combustibles.

Carburetted and *bicarburetted* hydrogen are invisible and highly inflammable gases, burning with a yellow flame. They are formed during the combustion of most kinds of fuel.

See diagrams 1 and 2, pages 71 and 74.

Notions of the Ancients Respecting Combustion. The ancient philosophers held an opinion that nature consisted of four elements, earth, air, water, and fire. They account for the ascending current of flame by supposing fire to be the purest and most perfect of the elements, forever tending upward to the *empyrean*, its own home of pure fire and light. This doctrine was taught and generally accepted until the middle of the 17th century, when a new theory was proposed by Beecher, a distinguished German physician and chemist. This theory was known as the Phlogistic Theory. It assumed that there existed in nature a rare ethereal substance called phlogiston. This could not be isolated, but was always present, and formed a constituent part of all combustible bodies. When a substance was burned, phlogiston escaped, and flame was its natural state; but soon it passed into combination with the atmosphere. This theory respecting the phenomena of combustion held undisputed sway, and was entirely satisfactory so long as philosophers ignored an experimental study of nature, and remained content in "swinging round in circles" or their own fanciful imaginations. But when Genius retired from the ideal world, and with the true spirit of inquiry commenced to interrogate the living universe, the first response pronounced the doctrine absurd, and the retorts and balance of Lavoisier gave it its death blow.

It ill becomes us to ridicule the doctrine of phlogiston, while thousands among us entertain notions respecting combustion quite as absurd. Notwithstanding the boasted enlightenment of the present age, and our one hundred thousand free schools, purporting to educate all classes of the community, it is truly astonishing how deficient is the information of all classes, even those who claim to be educated, respecting so familiar a subject as combustion. Ask what becomes of the vast quantities of wood and coal which are daily thrown into our stoves and furnaces, and in nine cases out of ten the reply will be, "*burned or consumed; burned to smoke and ashes.*" And when scientific men attempt by the aid of chemistry to present an enlightened view of the subject, they exclaim, "Away with your fine-spun theories and hair-splitting experiments. Give us something tangible, something practical;" just as if there is nothing real or practical respecting the combustion of fuel except smoke and ashes. *Positive fuel*, *comparative smoke*, *superlative ashes*, the *Alpha* and *Omega* of combustion. Nor can it be expected that the masses, or even those intelligent men connected with manufactories, managers of railroads, or directors of steam navigation, will possess a very large fund of reliable information concerning the combustion of fuel.

Rejecting the aid of science, they become the obedient pupils of a class of cackling patent mongers, who are deficient alike in knowledge and integrity.

The writer of these pages met, a short time since, a man who claimed to have discovered a method of burning, not only all the smoke, but all the gases formed in the process of combustion. On being asked what gases he burned, he replied, "All." "Do you burn the nitrogen and the carbonic acid?" "Certainly," was his prompt reply. "What do you mean by *burned?*" "Consumed." "What do you mean by *consumed?*" "Burned up — destroyed forever." This Socrates of the 19th century was instructing the benighted citizens of Boston that all former theories respecting combustion had been exploded, etc. His invention consisted of a small piece of wire gauze placed at the entrance of the smoke pipe.

With such teachers it is not a surprise that we hear people talking about burning smoke, burning the air, "burning the gases of the air," burning the oxygen of the air, etc. Let it be remembered by all, that smoke will not burn, nor will air burn, nor will carburetted hydrogen burn, nor will bicarburetted hydrogen burn, nor will carbonic oxide burn, nor will carbon burn, *unless brought into contact with other elements.*

There is not a "combustible" substance, either simple or compound, known in the universe; that is, there is no substance which possesses the inherent property of burning when taken alone. It is only when a body is acted upon by some other body that the phenomena of fire are possible.

"Combustibility is not a property of the combustible taken alone; it is merely a faculty that may be brought into action through the instrumentality of a corresponding faculty in some other body."

Experiment. Lower into a jar of pure oxygen a small piece of charcoal heated to incandescence. As it enters it brightens and glows with a pure white and brilliant light. It grows smaller and smaller, and after a time entirely disappears. What has become of this solid mass? We say that it has been consumed — burned up. What do we mean by this? Not that the atoms of which the carbon is composed have been destroyed or annihilated, for amid all the countless changes of nature not an atom of matter is destroyed or lost. If we examine the contents of the jar, we shall find that its weight has been increased by just the number of grains that the charcoal weighed; this shows us that the carbon is still within the jar, but in another form. If the contents are submitted to a chemical analysis, we should find that it contained carbonic acid, which is composed of two elements, carbon and oxygen, six grains of the former to sixteen of the latter.

Meaning of the Term Combustion. Combustion is the process in which two or more elements enter into chemical union, attended by the liberation of heat and light, and the production of a new compound or compounds.

Combustion, in the more popular or general acceptation of the term, is restricted to that form of rapid chemical action which occurs between the oxygen of the air and the carbon and hydrogen of certain organic substances, as wood, coal, and other varieties of fuel. The terms *burning* and *consuming* are common expressions for the same process.

Generally, except in cases of combustion, chemical action is brought about for the sake of obtaining some valuable products resulting from this action. Thus we effect the chemical union of sulphur and mercury to obtain the bright red paint called vermilion. But in combustion *the products* are regarded as worthless. In burning charcoal we cause carbon and oxygen to unite; not for the sake of the carbonic acid which is produced, but on account of the heat, which is only an *incidental result* of such an union. So in the case of illumination we bring about chemical action, not for the products formed, not for the heat, but for the light, which is another *incidental* result of chemical action.

Combustion will take place only when two or more substances which have an affinity for each other, are brought in close contact, and in the case of a fuel, a high temperature is indispensable. Any three of these conditions may be complied with, and still no combustion occur.

It has been stated that carbon, when at a high temperature, has a strong affinity for other elements. When, therefore, a bit of charcoal is heated and introduced into a jar filled with oxygen, the atoms which compose the exterior of the charcoal come in close proximity to the atoms of oxygen with which the jar is filled; these atoms are urged towards each other by the force of chemical affinity, and when they clash, this force is suddenly arrested and given out in the form of heat, just as when we strike a piece of iron with a hammer, the force of the blow is instantly arrested, and the energy is given out as heat. So intense is the heat developed by the clashing of atoms between the carbon and the oxygen, that the piece of carbon is kept at a white heat, and the compound formed by the union of its atoms escapes as carbonic acid. This prepares the way for other atoms to clash, and so the process continues until either the carbon or the oxygen, or both, are consumed.

When we say that a substance is consumed or burned, we mean that the substance has entered into combination with another substance, and through this combination heat has been evolved.

What Occurs in the Burning of Oil or Gas. Take the case of ordinary flame produced by the burning of gas or oil.

The chief constituents of these substances are carbon and hydrogen in a state of chemical union, called hydro-carbon. From this colorless gas escapes the soot-[illegible] which we see ascending from our lamps and gas-bur[illegible] is imperfect.

When we turn the stop-cock of a common gas-burner, the coal-gas (hydro-carbon) rushes out; the surface of the compound gas is brought into contact with the oxygen of the air, and by applying the heat of a burning match, chemical attraction is immediately called into action, and so intensified that the gas bursts into flame. At this high temperature the oxygen has an attraction for both the hydrogen and the carbon. It seizes upon the hydrogen first, evolves heat and produces water, while the carbon is set fire. A countless number of atoms of carbon are now floating in the midst of the burning mass. These become white hot, and to them, while in this state of intense incandescence, is the light chiefly due. But the carbon at this high temperature has a strong attraction for the atoms of oxygen which are constantly rushing towards the flame, induced thither by the current of ascending vapors; the atoms of the carbon unite with the atoms of oxygen; heat is developed, and an invisible gas, composed of six parts of carbon, and sixteen of oxygen is produced; this is carbonic acid,— that same substance produced by burning charcoal in oxygen.

Combustion therefore is a chemical change effected *upon*, but not an annihilation *of*, matter; for in each case the weight of the products formed will be found to equal that of the substances which we say are burned plus the amount of the oxygen which enters into combination with these substances.

In each case "we have atoms of dissimilar substances which are separated and powerfully attracted like lifted weights; they rush together, collision arrests motion, and their force is given out as heat. It is the clash or impact of the atoms of the oxygen against the atoms of the elements of the burning bodies which give us the light and heat of combustion. By figuring to ourselves the atoms shot across the molecular space with intense force and thus parting with their excess of motion, we have an explanation of the source of heat in combustion."

One circumstance renders it difficult for many people to realize that nothing is destroyed in the burning process.

They see that the solid, ponderable matter rapidly wastes away and disappears, and they infer that it must be lost.

This is because the products of combustion are *invisible*.

But we should bear in mind that matter may exist, notwithstanding that it is incapable of revealing itself to us through our sense of sight. Oxygen, for example, as well as the atmosphere from which it is derived, is invisible, yet no one doubts the reality of its existence.

How Combustion Changes Substances. Burning changes a visible or invisible compound substance and an invisible simple substance into one or more invisible compound substances. This is only another illustration of the law stated before, namely, that all chemical compounds are unlike their constituent elements. The two invisible gases, nitrogen and oxygen, combine to form a visible fluid.

The black solid, carbon, and the yellow solid, sulphur, form a colorless liquid. The products of combustion are not, however, *always* invisible; the product obtained from the combustion of hydrogen may be made visible. If we bring the invisible vapor in contact with some cold substance, it will be condensed into a liquid which possesses every property of pure water. Sometimes combustion affords a solid residue. Thus when phosphorus is burned in oxygen, a white powder resembling snow will be found in the bottom of the jar, which may be seen and weighed as easily as sugar or salt. If two grains of phosphorus are burned, the product (phosphoric acid) will weigh four and one half grains, and at the same time it will be found that exactly two and a half grains of oxygen have disappeared.

Combustible and Supporter. Many suppose that hydrogen, carbon, and other elements called *combustible*, possess some inherent quality which renders them capable of producing light, and flame, and heat; or are endowed with the property of burning, while atmospheric air is regarded as *a supporter of combustion.* But no one who has given the subject attention in the foregoing simple experiments can fail to see that such a distinction has no foundation whatever.

What Takes Place when we Kindle a Fire. We have a cold stove, cold fuel, cold air, and a cold match. We draw the match across a rough surface, the friction raises the temperature above 150°, at which point rapid chemical action takes place between the phosphorus of the match and the oxygen of the air; it bursts into a brilliant flame, developing heat sufficient to induce chemical affinity between the sulphur of the match and the oxygen of the air; they unite, a flame is produced, and sufficient heat is evolved to ignite the hydro-carbon which has been set free from the wood through the agency of the heat produced by the combustion of the phosphorus and the sulphur. The oxygen now seizes first on the hydrogen of the hydro-carbon, heat is sent out and water is produced. The atoms of carbon have now become heated to a white heat. They now unite with the atoms of the oxygen, evolving heat and forming carbonic acid. We now apply this burning match to the fuel, which must be a substance which contains volatile hydro-carbons, as the heat from the match would not be sufficient to ignite carbon.

It must also be in a state of fine division, because large surfaces would conduct away the heat of the burning match, so that no point would be

sufficiently heated to become ignited, but if the pieces are small, some sharp edge or point will readily take fire; the heat from these is communicated to other portions of the fuel, and if there is a due supply of air, the whole mass will in a short time commence to burn. To make a fire, then, we first ignite the match by friction. The phosphorus combines with the oxygen; heat is evolved through this combination, and phosphoric acid is produced; the sulphur unites with the oxygen, heat is evolved, and sulphurous acid is produced; carburetted hydrogen is driven off from the wood of the match; the hydrogen combines with the oxygen, heat is evolved, and water is produced; the carbon from the wood of the match unites with the oxygen, heat is evolved, and carbonic acid is produced; carburetted hydrogen is formed from the fuel; the hydrogen combines with the oxygen, heat is developed, and water is produced. The carbonaceous portion of the hydro-carbon unites with the oxygen, heat is evolved, and carbonic acid is produced. When all the volatile hydro-carbons have been consumed, no flame will be seen, but the carbon is in a state of incandescence and continues to burn until the whole is consumed.

Quantity of Heat. The quantity of heat evolved depends upon the number of atoms of oxygen *brought into action;* therefore, that substance which enters into combination with the largest volume of oxygen will evolve the most heat.

Thus every ounce of hydrogen in burning combines with eight ounces of oxygen, while an ounce of carbon will absorb only two and two-thirds ounces of oxygen; consequently, the heating power of hydrogen is to carbon as three to one. The calorific power actually obtained by experiment does not quite agree with the foregoing statement, but the apparent discrepancy may arise from the difficulty of rendering available all the heat developed by chemical combination.

The quantity of water raised one degree by the combustion of a given quantity of these substances indicates only an approximation to their real heat-producing powers, as it is somewhat difficult, in performing the experiment, to exclude all disturbing influences. The results obtained are always under the true value, in consequence of the losses which are sustained. By glancing at table 3, page 36, it will be seen that the heat evolved by the combustion of hydrogen is more than four times that of an equal weight of carbon. These results nearly agree with those obtained by the researches of Favre and Silbermann.

Others assign a greater heating power to carbon, even as high as 21,603, because they claim that nearly one fourth of the heat evolved is rendered latent on effecting the gasification of the carbon. If this last view of the case be correct, the total calorific power of carbon is to that of hydrogen as the quantities of oxygen with which they respectively enter into combination.

Temperature Required for Ignition. A very interesting peculiarity of ordinary combustion is the fact that its beginning requires a *high temperature.* We consider coal, wood, oil, sulphur, and gunpowder very combustible; but there is no combustion, although oxygen is present, until they are set on fire and heated or ignited; that is, until some portion is heated to a high temperature. Oxygen is very different from other supporters of combustion in this respect, for with them combustion begins at ordinary temperatures. If chlorine were suddenly put in the air in place of oxygen, or if the oxygen should assume its active form known as ozone, everything combustible upon the earth would take fire and be consumed with fervent heat in a few hours.

The temperature of ignition varies greatly for the different combustibles. Phosphorus, sulphur, and sodium take fire below a red heat; while the ignition point with others is so high that we rarely have any opportunity to see them burn. The combustible nature of iron, copper, lead, gold, and silver was not even suspected until a recent period. We know now that they burn more readily and fiercely than any common fire, when they are once kindled. If we wanted to make the most gorgeous pyrotechnic display possible, it would be done by making a bonfire of a few tons of iron in an atmosphere of oxygen. The ignition temperatures have been determined for only a very few substances. Phosphorus ignites at 150°; sulphur at 480°; hydrogen begins to burn at 300°; carbon requires 800° or 1,000°· carburetted hydrogen, 1,000°.

ANALYTICAL TABLE EXHIBITING THE CALORIFIC POWER OF SOME OF THE ELEMENTS AND COMPOUNDS WHICH ENTER INTO CHEMICAL UNION WITH OXYGEN, ALL OF WHICH ARE EMPLOYED IN THE COMBUSTION OF FUEL.

NAMES OF THE ELEMENTS AND COMPOUNDS.	No. of Parts of Water Heated 1° F. by the Combustion of 1 Part of the Substances.
Hydrogen in combining with oxygen to form water	64832
Carbon in combining with oxygen to form carbonic acid	14432
Carbon in combining with oxygen to form carbonic oxide	4530
Carbonic oxide in combining with oxygen to form carbonic acid	9902
Bi-carburetted hydrogen in combining with oxygen to form water and carbonic acid	21632
Carburetted hydrogen in combining with oxygen to form water and carbonic acid	27032

For full table see page 36.

RECAPITULATION.

Combustion is a form of chemical union which is attended by the disengagement of heat and light.

In cases of ordinary combustion the action takes place between the oxygen of the air and the elements of certain organic bodies, as wood, coal, etc.

Combustion requires that there should be at least two substances.

The substances must have an affinity for each other.

They must be in close proximity to each other.

One or both must be at a high temperature.

When hydrogen enters into chemical combination with oxygen, water is produced.

When carbon unites with the largest measure of oxygen, carbonic acid is produced.

When the compounds of carbon and hydrogen burn, the hydrogen and oxygen first unite to form water, then the carbon and the oxygen to form carbonic acid.

The weight of the products of combustion is always equal to the weight of the combustibles, plus the weight of the oxygen absorbed.

The quantity of heat evolved is in proportion to the quantity of oxygen which enters into chemical union.

Perfect combustion occurs when every atom of the combustible enters into chemical union with its equivalent of oxygen.

The products of perfect combustion are water in the form of an invisible vapor and carbonic acid.

The products of imperfect combustion are: Water, carbonic acid, smoke, carbonic oxide, and other combustible gases.

All the products of the perfect combustion of fuel are invisible.

All the products of imperfect combustion are invisible, with the exception of true smoke; that is, of minute particles of pure carbon.

The temperature of ignition varies greatly for different substances. Iron, copper, lead, gold, and silver are combustible, and will burn. The ignition temperatures have been determined for many of the substances. See full table, No. 4, of the *ignition*, *melting*, *boiling*, and *freezing* points, also color due to heat.

CHAPTER V.

SEPARATION OF THE FUEL PREVIOUS TO COMBUSTION.

LET us commence at the beginning and inquire into the nature of the process to which our materials are submitted, and understand their respective wants and conditions during that process. Then, and not until then, shall we be qualified to determine the form, dimensions, and peculiar structure of the apparatus best adapted to the operation.

Nature of the Process. We are to bring about chemical action between oxygen and the several elements of compound bodies derived from the different varieties of fuel.

The oxygen is derived from the atmosphere. Our object is to obtain the maximum amount of available heat from a given quantity of fuel. This requires perfect combustion.

Perfect combustion can only be secured when every atom of combustible matter finds its equivalent of oxygen and enters into chemical union with it. The furnace should be constructed with reference to the conditions required for securing this result.

The elements which are to combine with the oxygen are carbon and hydrogen, or compounds of these.

As bituminous coal presents a greater number of impediments to perfect combustion than any other variety of fuel, we have selected it for examination, and shall attempt to point out the conditions required for its complete consumption.

It is not necessary to enter into detail respecting the various compounds which are formed in different proportions during the combustion of coal, or their effects upon the process. It is sufficient for our purpose to know that all these compounds, except those formed of carbon and of hydrogen, are injurious to combustion.

Carbon and hydrogen unite in several proportions, and form many curious and important compounds, among which it is difficult to distinguish those which ought to be considered as distinct and definite combinations from others which a[illegible]easures of the former.

These compounds are generally called hydrocarbons, and amongst them are some striking illustrations of one species of isomerism; that is, of compounds often differing essentially in their physical or chemical properties, or both, and yet apparently produced by the union of the same elements and bearing the same relation to each other.

How Bituminous Coal Burns. In the natural state of bituminous coal, the bitumen and carbon are united and solid.

If we take a piece of charcoal and immerse it in boiling pitch or rosin until its pores are filled with these substances, we should have a material resembling bituminous coal.

On entering into combination the rosin would be separated from the charcoal before the former could be converted into flame or the latter ignited, nor would the charcoal burn until the resinous matter had been consumed. The wick of a lamp does not burn while there is a supply of oil.

Alcohol may be burned on a piece of paper, but the paper will not be consumed nor acted upon in the least while there is a supply of alcohol; but after the alcohol has been consumed the paper will take fire. This is the case with bituminous coal. It is not a homogeneous mass which is to enter into combustion, and the conditions and wants of each part are essentially different. This is a primary distinction which demands special attention, for to the neglect of this may be attributed many of the erroneous practices into which so many have fallen in the construction and management of furnaces.

Important Facts. In entering upon an investigation of this subject, the reader should keep distinctly in view the following facts: 1st. Bituminous coal consists of carbon and bitumen. Bitumen is composed essentially of carbon and hydrogen. 2d. Coal cannot be ignited while in a state of solid coal; that is, while these two parts are united. The bituminous portion, like oil or tallow, will burn only as it is converted into the *gaseous state*. The former burns with flame, the latter not.

Destructive Distillation. Hence combustion in the furnace consists of two distinct processes:—

1st. *The destructive distillation of the fuel.*

2d. *The chemical union of the different products of the distillation with the oxygen of the air.*

When wood is heated in a closed vessel, or with only a limited supply of air, the organic structure of the wood is destroyed, and a large number of volatile compounds are driven off. This process is called the destructive distillation of the wood.

The number and character of these compounds depend on the nature of the wood and the degree of heat to which it is subjected.

Change Previous to Combustion. The bitumen of the coal, on account of the large amount of hydrogen which it contains, absorbs heat very rapidly, and the coal is changed into a viscous semi-fluid or pitchy state, and by a greater increase of the heat to the gaseous state. Now, all this large quantity of heat which is absorbed becomes latent in the gas, and is wholly unavailable until the gas enters into chemical union with the oxygen, and is consumed. See page 13.

If we watch carefully this process of gasification, we shall observe that, as long as any of the volatile gases remain to be evolved, the solid portion remains until the former has been consumed or removed. The whole process is well illustrated in our gas-making establishments, where are exhibited the relative proportions of these two distinct parts of at least one variety of fuel, viz. bituminous coal, and where is also shown that an enormous quantity of heat is required to effect this change, as two thirds of the whole solid portion or coke is used in producing the separation of these hydrocarbons.

Just the same expenditure of heat must take place when we effect a separation, and expel the volatile portion from coal in a furnace. There is, however, the difference in a *retort*,—no loss of heat is sustained, because the gas, on being liberated, is collected and stored in the gasometer for subsequent use; but no arrangement has been made for retaining it in the furnace; consequently much heat is lost.

Thus, after the volatile portion of the coal has absorbed so much heat as to reduce the temperature of the interior of the fire chamber below the point of ignition, the volatile or gaseous portion, which is set free, whether in a retort or a furnace, is always associated with several other substances, tending more or less to diminish its heat and light giving properties. In gas-making establishments these impurities are removed by a process called purification; but in a furnace this purification cannot be obtained, and hence the entire gaseous products of the coal, good and bad, are indiscriminately mixed and consumed, *or carried away* to the chimney as they are generated.

This important feature seems to have been overlooked in the construction of furnaces. It has been a current opinion that anthracite coal, which contains a smaller portion of this volatile matter, possesses greater heating properties than other varieties; yet numerous experiments show that more heat can be evolved from the combustion of a given number of pounds of bituminous coal than from the same number of anthracite coal, provided w[illegible]ome the physical and chemical impediments to perfect comb[illegible] are inherent in the bituminous, but do not exist in the a[illegible]

In some localities where only bituminous coal can be obtained, the coke alone is used for locomotive purposes.

On account of the practical difficulties in rendering the heating powers of the volatile portions available, the coal is placed in ovens, and the entire gaseous portion is expelled at the expense of an enormous waste of fuel, to say nothing of the cost of the operation itself.

This is destructive distillation *without atmospheric contact.* When air is present, as is the case in a furnace, the separation of the gaseous and carbonaceous parts takes place in the same manner; and these volatile hydrocarbons will be consumed, or pass off unconsumed, according to the way in which the oxygen is supplied. The character of the two parts and their manner of entering into combustion is essentially different.

The general impression is that coal enters into combustion *at once* on the application of heat, and during the process it evolves the gaseous matter which it contains. This view, however, is not correct, and fails to comprehend a very important feature of the consumption of fuel; viz. the order in which the solid and gaseous portions enter into combination with oxygen.

When fresh coal is thrown upon a fire, the general temperature is lowered and not raised, as would be the case if this additional mass of fuel were brought immediately into activity.

A large portion of heat is first absorbed in producing the expansion and volatilization of the coal, and it has been ascertained that the absorption of heat will be in an exact ratio to the quantity of gases generated. This process of generating the gases, called volatilization, is one of the most cooling in all nature, because a large quantity of heat is converted directly from the sensible to the latent state.

There is great danger of underrating the quantity of heat absorbed and rendered latent by the expansion and volatilization of the bitumen of the coal. Evaporation and gasification are the most effective means of producing an extremely low temperature. A little ether placed upon the hand evaporates rapidly, and absorbs so much heat that a sensation of cold is felt. Carbonic acid gas becomes a liquid under a certain pressure. If the pressure be removed, it returns to the form of a gas with such rapidity that, if mercury be brought in contact with it, it is frozen, and may be hammered like a piece of lead. In this way water may be frozen on a red-hot crucible.

Cause of Smoke in the Lamp and Furnace Identical. There is a deficiency in the supply of pure air at the time, at the place, or in the manner, that will enable the elements of the hydrocarbons to enter into chemical union with oxygen. If the arrangements of our lamps could be so changed as to prevent these evils, it remains to be proved why our furnaces may not.

Dr. Franklin proved that two small wicks placed in two candles, and burnt side by side, will give more light than if they were combined in one candle. Very large wicks convert the oil of a lamp into gas faster than the air can consume it.

Camphene and kerosene are superior illuminating substances, but they cannot be burned in the ordinary way, because they contain so large a proportion of carbon that they smoke excessively. This is the case with the furnace; a proper supply of air cannot mingle with the inflammable gases before they have passed into a region where the temperature is too low for their chemical union with oxygen.

Argand's Invention. Ami Argand, of Geneva, conceived a plan by which this evil may be remedied, so far as lamps are concerned. He made the wick hollow, so as to burn in a ring or circle, and thus admitted a current of pure air to the centre of the flame, whereby this dark central cone of unburned gases is avoided and the area of contact of the air nearly doubled.

Petroleum and other oils, which in an oil lamp produce a long conical flame, of a dull murky red color, burn in this lamp with a short white and intensely brilliant flame. Cut off the supply of air from the interior, and, notwithstanding the free supply of air on the exterior, the flame becomes instantly dull, red, and smoky, with little heating or illuminating qualities.

Now, the cause of this imperfect combustion is not a lack of air, but the slow rate of mixture occasioned by the want of an adequate amount of contact surface between the inflammable gas and the oxygen. By preventing the admission of air to the centre of the lamp, the gases generated from the inside of the wick are decomposed by the white-hot flame that surrounds them, but no air reaches them there; they ascend rapidly, and, before they can become mingled with a sufficient quantity, they are reduced to a temperature too low for chemical action, and hence pass away unconsumed — the hydrogen as an invisible gas and the carbon in a state of minute solid particles or true smoke. When the air is admitted to the inside, the accessible contact surface for the clashing of atoms is nearly doubled, and the long smoky flame instantaneously becomes short, white, and highly luminous, with a great increase of heat for the same expenditure of oil. The most powerful lamp furnace in use for the laboratory is constructed upon this principle.

RECAPITULATION.

Bituminous coal consists of two distinct parts — the bitumen, or volatile portion, and the carbonaceous or solid portion.

The former will enter into union with oxygen only in the aeriform state, the latter only in the solid state.

Neither are capable of being ignited when combined.

A fresh charge of coal, on being thrown into the furnace, absorbs a large amount of heat, which has been derived from the combustion of some previous charge.

This heat expands the bitumen, and changes it from a solid to a viscous semi-fluid, resembling pitch or tar.

By further absorption of heat, this viscous mass is expanded into an enormous volume of gas, consisting mainly of carburetted hydrogen.

As ice will absorb a large amount of heat until converted into water, and water continue to take up heat until converted into steam, so the bitumen in coal will continue to absorb heat until changed from a solid to a semi-fluid, and from a semi-fluid to a gaseous state.

The carbonaceous portion remains unconsumed until the volatile part has been expelled. The order of these distinct processes is as follows:—

1st. The expansion and fusion of the bitumen.

2d. The generation of an immense volume of gas.

3d. The absorption of a large quantity of heat during these changes.

4th. The combustion of the gaseous portion.

5th. The combustion of the carbonaceous portion.

The cause of smoke in the furnace and lamp is identical; there is a *deficiency in the supply of pure air.*

If the arrangements of our lamps could be so changed as to prevent these evils, it is a clear inference that our furnaces may also be made *smokeless and economical.*

For both lamps and furnaces there must not only be a sufficient supply of air, but there must be a due mixture of the air and the gases at the time, at the place, and in the manner that *will insure chemical union.*

CHAPTER VI

VOLATILE CONSTITUENTS OF COAL

PROPORTION OF EACH CONSTITUENT. The volatile products evolved from coal by heat are hydrogen, carburetted hydrogen, bi-carburetted hydrogen, carbonic acid, a small percentage of nitrogen, ammonia, and other substances.

The exact proportions of each of these depend on the variety of coal, and also on the intensity of the heat applied. Frequently the proportion of carburetted hydrogen is as great as 83 per cent of the whole; and at a very high degree of heat, and during the latter stage of the process, the proportion of hydrogen is increased, in some instances to 20 per cent, though the percentage is generally much less, while the amount of bi-carburetted hydrogen seldom exceeds 10 per cent.

We see, then, that the main bulk of coal gas is carburetted hydrogen; for the only difference between carburetted and bi-carburetted hydrogen is in the proportion of hydrogen which they contain, as carburetted hydrogen is composed of *two* equivalents of *hydrogen* and *one of carbon*, and bi-carburetted hydrogen of *two* equivalents of hydrogen and *two* of carbon, while there is generally a sufficient amount of pure hydrogen produced to convert the bi-carburetted into carburetted hydrogen if united with it; and it makes no difference for purposes of combustion whether this hydrogen be in a state of chemical union or not, as the two elements are separated in burning. We are therefore warranted in the conclusion that the principal part of the volatile constituents of coal, amounting to 80 or 90 per cent (excluding impurities), *is carburetted hydrogen.*

Quantity of Gas Obtained from a Ton of Coal. From information gathered at our gas-making establishments, we find that no less than ten thousand cubic feet of gas are obtained from one ton of bituminous coal. We must bear in mind that this coal gas is the same, whether generated in the retort or the gas-house or the furnace, excepting that the impurities are removed previous to combustion in the former case and not in the latter.

When we remember that this ten thousand feet of gas, if brought in contact with the air through a well-adjusted argand or other burner, is capable of producing an immense heating and illuminating effect, and that the coke, which remains after the volatile matter has been expelled, will burn without smoke, and produce an intense heat; and when we see these two valuable constituents, united in the form of coal, thrown into a furnace, and so imperfectly burned that the smoke escaping from the chimney becomes a positive nuisance, so that in many cases the whole of the ten thousand feet of gas are expelled, and only the remaining coke is made use of, we can but conclude that there is something radically wrong in the construction of our furnaces.

That this is the case will become evident as we proceed with our investigations; and our object will be to show how the volatile portion of the coal may be burned as completely in the fire chamber of a steam boiler as in the jet from a gas-pipe.

What is it that is required to consume and render available for purposes of heat this huge volume of gaseous matter? Simply to meet those conditions which are required to cause every atom of carbon and hydrogen contained in it to find and enter into chemical union with their respective equivalents of oxygen.

These conditions may be briefly stated as follows: —

1st. That there must be a due supply of *oxygen*, as determined by the laws of chemical combination.

2d. That there must be admitted a sufficient quantity of atmospheric air to supply this oxygen.

3d. *That this air must be pure.* It must not be deteriorated by being deprived of a part of its oxygen, nor contaminated by the products of some previous combustion.

4th. That this air must be admitted at the *time*, at the *place*, and in the *manner* which will bring the atoms of hydrogen and oxygen and of carbon and oxygen within the sphere of chemical attraction.

5th. That due regard must be had for the temperature required to produce chemical action between the hydrogen and the oxygen and the carbon and the oxygen. See also page 32.

The Quantity of Air Required. The first step towards effecting the complete combustion of coal gas is to ascertain the quantity of oxygen with which its elements will enter into chemical union. This question cannot be decided by the dictum of any chemist, or by the ingenious contrivances of any mechanical engineer; for "it was foreordained and predestinated from the foundation of the world" that these elements should enter into chemical union only in fixed and definite proportions. This branch of our subject is not then made up of a "complicated tissue of uncertainties," but, independent of all specula-

tion, is reduced to a matter of unerring calculation. As it has been stated, carburetted hydrogen is a compound gas, consisting of two equivalents of hydrogen and one of carbon.

The weight of an atom of hydrogen is one, that of carbon six; but the volume, or bulk, of an atom of hydrogen is double that of an atom of carbon; and these, when in a state of chemical union, are condensed into two fifths of their previous bulk, or into the bulk of a single atom of hydrogen. See page 32, par. 8.

1 atom of Carburetted Hydrogen, weight 8, consists of $\begin{cases} \text{1 atom of Hydrogen, weight 1.} \\ \text{1 atom of Carbon, weight 6.} \\ \text{1 atom of Hydrogen, weight 1.} \end{cases}$

Now it has been shown that this compound gas, on entering into combination, becomes decomposed, and that its constituent elements unite with oxygen by different processes. It is, therefore, important that we examine their respective weight, volumes, and other properties.

1st. The Volume of the Oxygen Required for the Combustion of the Hydrogen of a Given Volume of Carburetted Hydrogen. One atom or equivalent of hydrogen requires one atom or equivalent of oxygen, but there are two atoms of hydrogen in every atom of carburetted hydrogen; therefore, for the combustion of the *hydrogen* of every atom of carburetted hydrogen, two atoms of oxygen are required.

But since the *bulk* of an atom of hydrogen is just double that of an atom of oxygen, for the combustion of the hydrogen of a given volume of carburetted hydrogen it requires a *volume* of *oxygen* equal to exactly *one half* that of the *hydrogen*. If, for example, we have one cubic foot of carburetted hydrogen, we shall obtain, after decomposition, two cubic feet of hydrogen, the combustion of which will require *one* cubic foot of oxygen; and the oxygen and hydrogen, after their chemical union, will be condensed into two cubic feet of steam. See diagram 4, page 79.

2d. The Volume of Oxygen Required for the Combustion of the Carbon of a Given Volume of Carburetted Hydrogen. One atom of carburetted hydrogen contains one atom of carbon. When we burned carbon in the jar of oxygen, carbonic acid was produced. This consists of two atoms of oxygen for every atom of carbon, and these three atoms are condensed, after chemical union, into two thirds their original bulk, as follows: — See diagram 2, page 74.

1 atom of Carbonic Acid, weight 22, consists of $\begin{cases} \text{1 atom of Oxygen, weight 8.} \\ \text{1 atom of Carbon, weight 6.} \\ \text{1 atom of Oxygen, weight 8.} \end{cases}$

Then for the combustion of the atom of carbon contained in an atom of carburetted hydrogen, it requires two atoms of oxygen, or a volume of oxygen double that of the carbon. See diagram 5, page 81.

Since the bulk of an atom of oxygen is only one half that of the hydrogen, the volume of these two atoms is exactly equal to that of one atom of hydrogen, or one half the volume of the hydrogen in an atom of carburetted hydrogen; it therefore requires the same volume of oxygen for the carbon as for the hydrogen of the carburetted hydrogen, hence for both, double the volume; or for every foot of coal gas, two feet of oxygen. Therefore, for the complete combustion of the ten thousand feet of this gas, obtained from a ton of coal, twenty thousand feet of oxygen must be provided. The number of atoms employed in the combustion of one atom of coal gas, and their relative volumes and weights may be shown in a condensed form, thus: —

THE VOLATILE CONSTITUENTS OF COAL.

FIRST CONSTITUENT OF CARBURETTED HYDROGEN.

Hydrogen.				Oxygen.						
Vol.	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*
2	2	2	unite with	1	2	16	forming steam	2	2	18

SECOND CONSTITUENT OF CARBURETTED HYDROGEN.

Carbon.				Oxygen.						
Vol.	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*
½	1	6	unite with	1	2	16	forming carbonic acid	1	1	22

The Quantity of Air Required to Supply the Necessary Volume of Oxygen. Atmospheric air is composed of one atom of oxygen for every two atoms of nitrogen, but the bulk of an atom of nitrogen is double that of oxygen; therefore, the *volume* of the nitrogen in the air is four times that of the oxygen, as follows: —

1 atom of Atmospheric Air, weight 36, a mechanical mixture of $\left\{\begin{array}{l}\text{1 atom of Nitrogen, weight 14.}\\ \text{1 atom of Oxygen, weight 8.}\\ \text{1 atom of Nitrogen, weight 14.}\end{array}\right.$

Hence, to obtain one cubic foot of oxygen for purposes of combustion, we are obliged to make use of five feet of atmospheric air. Then, to obtain the twenty thousand cubic feet of oxygen, necessary for the complete combustion of a ton of coal, requires five times twenty thousand, or *one hundred thousand feet of air.* It must not be supposed that ten thousand cubic feet is the exact amount of gas given off from one ton of coal during combustion. Besides, this contains a percentage of bi-carburetted hydrogen and carbonic oxide, which somewhat varies the amount of the air required; yet this is sufficiently accurate for purposes of illustration. It has then been shown beyond doubt or contradiction: —

1st. That every volume of carburetted hydrogen requires for its complete combustion two volumes of oxygen.

2d. That it requires five volumes of air to furnish one volume of oxygen; hence ten volumes of air for the combustion of one volume of carburetted hydrogen.

3d. Not less than ten volumes of air will satisfy the conditions of perfect combustion.

If an excess of air be admitted, it passes through the furnace uncombined, absorbing and carrying with it a quantity of heat.

If *less* is provided, it is evident that a portion of the carburetted hydrogen must pass off unconsumed. See diagram 2, pages 74 and 75.

Structure of Flame. That currents of inflammable gases do not mingle rapidly with air may be shown by a variety of experiments.

The common lamp or candle furnishes illustration of the reluctance which air exhibits in mingling with inflammable vapors.

Dr. Reid tells us that the flame of a candle is produced by gas formed around the wick acting on the oxygen of the air, the flame being confined to the exterior portion of the ascending gas. All without is merely heated air and products of combustion; all within is unconsumed gas, waiting its turn to mingle with the oxygen of the atmosphere.

We might also quote Sir Humphrey Davy, Professor Daniels, Dr. Thompson, Faraday, and Tyndall, in corroboration of the main facts here stated.

1st. That the dark cone observable in the centre of the flame is a body of highly heated inflammable gas; that it is ready for combustion, and is only waiting its turn to become commingled with the oxygen of the air.

2d. That the portion of gas which becomes sufficiently mingled with oxygen is confined to a very thin shell surrounding the central cone; and that surrounding this is a faintly luminous envelope which contains the products of combustion.

3d. That the inflammable gas at the centre cannot burn, because little or no air reaches it, and the air which does penetrate so far, has given up its oxygen in passing through the thin shell where combustion is going on.

4th. If so small a volume of gas obtained from the wick of a candle, which has free access to the air on all sides, finds difficulty in coming in contact with an adequate supply of oxygen, how can we expect the enormous bulk of the gas generated in a furnace to effect the required mixture when the supply of air is restricted to one side, and the whole under the opposing influence of a strong upward current?

RECAPITULATION.

The main bulk of the volatile constituents of coal is carburetted hydrogen. Nearly ten thousand feet are produced from every ton of bituminous coal. This coal possesses great heating and illuminating properties.

The coke burns without smoke, and evolves an intense heat.

The perfect combustion of the two constituents of coal requires: —

1st. A supply of *pure* air sufficient to furnish the adequate volume of oxygen.

2d. This air must be admitted at the *time*, at the *place*, and in the *manner* which will bring the atoms of oxygen and hydrogen and of carbon and oxygen *within the sphere of chemical attraction.*

3d. Due regard must be had for the temperature required to induce chemical action between the "*combustible*" and the "*supporter.*"

For the complete combustion of the *volatile* constituents of a ton of coal *one hundred thousand cubic feet of pure air is required.*

Too limited a supply of air occasions a loss of combustible gases, or their hydrogen enters into union with oxygen, and the carbon escapes as smoke.

An excess of air robs the fire chamber of heat, and prevents complete combustion, by reducing the temperature below the point at which rapid chemical action is possible.

ANTHRACITE COAL.

GAS COKE.

These cuts show the form and structure of hard coal and that of coke after the gas has been driven off (in ovens) or in the furnace of the steam boiler, where the gas and coke are burned together under the conditions so fully explained in the foregoing pages.

For full table of analysis and value of coal, coke, and other fuels, see page 28.

CHAPTER VII.

CHARACTER OF THE COKE. VOLUME OF AIR REQUIRED.

THE COKE. Having shown the quantity of air required for the combustion of the volatile portion of the fuel, we will now consider the subject with reference to the solid carbon which remains after the gaseous portion has been consumed, or, as is too often the case, *carried away unconsumed.* The solid part which remains does not differ essentially from the coke which comes from the retorts of the gas-making establishments. This is chiefly carbon, but not pure carbon, as there is always a percentage of earthy matter left after combustion. Carbon is the only heat-giving element contained in the mass. Carbon unites with oxygen in different proportions, giving rise to three distinct compounds.

These are carbonic acid, carbonic oxide, and oxalic acid. Only the first and second are formed during the combustion of coal. We have already referred to the first. It is composed of two equivalents of oxygen and one of carbon.

It is a colorless, odorless gas, neither a combustible nor a supporter of combustion. It will extinguish the flame of burning bodies, even when mingled with four volumes of air. This property of carbonic acid has rendered it serviceable in extinguishing fires in coal mines. In one of these mines in England a fire which had continued for thirty years was extinguished by the use of this gas. The carbonic acid was generated by passing a current of air through a furnace of coal, and blown into the mine until all the passages were filled with it, and further combustion prevented. The weight of carbonic acid is a little more than one and a half times that of air (air 1, carbonic acid 1.529).

Quantity of Oxygen Required. From the unchangeable law of chemical combination it follows that the production of carbonic acid from the solid carbon will necessarily be the same as in the case of the carbon found in the carburetted hydrogen.

Every atom of carbon requires two atoms of oxygen for the formation of carbonic acid. If the weight of an atom of carbon be six, that of each atom of oxygen will be eight.

Therefore, for the combustion of six pounds of carbon, sixteen pounds of oxygen will be required.

Assuming that the coke has 80 per cent of the weight in a ton of coal, we shall have sixteen hundred pounds of coke. As it requires sixteen pounds of oxygen for the combustion of six pounds of carbon, for sixteen hundred pounds of carbon it will require forty-two hundred sixty-six and two thirds of oxygen. Now, one pound of oxygen at a temperature of 60° contains nearly eleven and one-fourth cubic feet, and forty-two hundred sixty-six and two-thirds pounds will contain forty-eight thousand cubic feet. But since the oxygen of the air is diluted with four times its bulk of nitrogen, it will require five times forty-eight thousand, or *two hundred and forty thousand, cubic feet of atmospheric air* for the complete combustion of the sixteen hundred pounds of coke. It has already been shown that it requires *one hundred thousand cubic feet of air* for the combustion of the gases generated *previous to the combustion of the solid mass.* Adding this to the two hundred and forty thousand cubic feet needed for the coke, we have an aggregate volume of *three hundred and forty thousand* cubic feet of atmospheric air required for the combustion of a ton of bituminous coal. *This would make a column of air more than sixty miles in length and a foot square.* This estimate is by far too low for practical application. For it will be noticed that this is the *minimum* quantity which will effect complete combustion, independent of any excess of air which may enter through the furnace. This estimate is also made on the supposition that the temperature of the air is 60°; but, on passing between the heated bars of the grate, and among the incandescent coal, it becomes heated, and its volume greatly expanded. If a larger proportion of air than combustion requires be forced through the furnace, the excess of air, passing through the fire, hinders combustion by carrying away heat, and by cooling the ignited surface of the carbon. It thus attracts the oxygen less strongly, and in consequence the fire languishes or deadens, as we say. If the furnace be supplied with less than the required volume of air, particles of carbon fly away as soot and smoke. We might suppose that this would be the only loss sustained. This would be true if carbonic acid were the only compound formed by the union of carbon and hydrogen. There is, however, another and most important state in which carbon combines with oxygen and passes away. This is a compound known as carbonic oxide.

It has been shown that the quantity of heat obtained from quantity of fuel will be in proportion to the amount of o which it can be made to unite. Since carbon unites with or the amount of oxygen in the formation of carbonic oxide th the formation of carbonic acid, it follows that only half

will be evolved in the formation of the former as the latter. In other words, carbonic oxide is carbon half consumed. It is therefore a combustible gas, and, unless some means are devised for effecting its combustion, a very serious loss will be sustained.

How Carbonic Oxide Burns. The combustion of this gas is just as distinct a process as that of carburetted hydrogen, and it demands all the preparatory conditions; viz. a definite supply of air, mixture previous to combustion, and a high temperature. In stoves where all the air is admitted through the grate, and forced to pass over the burning fuel, carbonic oxide is always generated in greater or less quantities. As it rises to the surface, it usually comes in contact with small quantities of air entering through the cracks about the door or other small openings. See diagram 3, page 77.

The gas here ignites and burns with a flickering, pale blue flame. This phenomena may always be seen in an anthracite or charcoal fire just after fresh coal has been added.

If this gas find a supply of air at the top, it is all consumed; that is, combines with another volume of oxygen and is converted into carbonic acid. In this case no loss of heat is sustained. If one half or one fourth of the required quantity of air is present, only one half or one fourth is consumed. If the carbonic acid find no air in the surface, it escapes unconsumed · yet, since it is invisible, the combustion seems to be complete.

Burning Smoke. The formation of carbonic oxide from carbon and carbonic acid in the furnace has led many practical men astray. The stove and furnace doctors of the day have filled the country with contrivances for "*the burning of smoke*," for "*the combustion of smoke*." We claim, and shall hereafter attempt to show, that this is absurd. We will here mention only one of the numerous errors into which these men have fallen.

When, from an insufficient or a redundant supply of air, or from other causes, combustion is incomplete, the carbonaceous constituent of the coal is set free in the form of smoke. This smoke is made to pass over heated bars of iron, or other heated substances, and, as we are gravely told, is *consumed*.

Carbonic acid is always mingled with the smoke, and when the two [illegible] brought together at a high temperature, as by contact with these substances, the *invisible* carbonic acid and the *visible* smoke unite [illegible] e described) and produce *invisible* carbonic oxide. [illegible] believe, is "*burning the smoke;*" but in truth the [illegible] ithout saving the smallest fraction of the heat.

Why This Carbonic Oxide Does Not Burn. It may be asked why the carbonic oxide, thus produced, does not ignite at this high temperature. It does not, simply, because there is no oxygen to unite with it. If a sufficient supply of oxygen had been present, it would not have been produced. If oxygen is admitted, it takes fire and heat is evolved.

Since carbonic oxide has already taken one equivalent of oxygen, it inflames at a lower temperature than either hydrogen or carburetted hydrogen. It is often sufficiently heated after passing to the mouth of the chimney to ignite on coming in contact with the air. This accounts for the flame which is frequently seen at the tops of chimneys, or of the smoke pipe of steam vessels. This fact should be sufficient to teach us, that *heat alone* will not effect the combustion of these combustible products of imperfect combustion. *Oxygen* is required, and we might as well attempt to overthrow the laws of gravitation as to burn these substances without it.

Quality of the Air. When we speak of furnishing a given volume of hydrogen for a given amount of coal gas or of coke, we do so because the laws of chemical combination require just this amount in order that every atom of both gases may enter into union and produce complete combustion.

We also speak of a given volume of common air as being sufficient to supply the required quantity of oxygen. We do so, knowing that the volume of *pure* air will contain a definite proportion of oxygen.

When we say that *ten* cubic feet are sufficient to effect perfect combustion with *one* cubic foot of coal gas, we state this on the supposition that the ten cubic feet of air contain 20 per cent, or two cubic feet, of oxygen. If this atmospheric air has been deprived of part of its oxygen or mixed with any other simple or compound substance, it no longer sustains the character of pure air, nor does it satisfy the conditions of complete combustion. Hence, if it can be shown that a portion of the oxygen is withdrawn from the air before it comes in contact with a large portion of the coal gas, and the carbon in the fire chamber, it is evident that complete combustion is impossible.

In this case certain quantities of hydrogen and carburetted hydrogen escape uncombined for the want of a proper supply of oxygen, and consequently a large amount of heat is lost. That the air is thus vitiated, or deprived of a part of its oxygen, will be shown in another portion of this treatise.

Mr. Parkes, in "The Transactions of Civil Engineers," observes that he found that smoke increased by the admission of air, the pressure of steam fell in consequence, and failure was unavoidable. On examination he found that failure could be traced to the *deterioration* of the air in passing over the inflamed fuel.

"In illustration of this, let us suppose that 100 represents the quantity of air required per minute for the perfect combustion of the gaseous products; and that 200 represents the quantity required for the use of the carbon on the grate. Let us further suppose that, instead of sending each of those quantities *separately* to perform its respective duty by giving up its constituent oxygen to its proper combustible (and for which express duty it was employed), we send the entire quantity, say 300, through such burning mass of solid carbon; can we doubt that the result would be, first, the impelling this latter to an increased and undue action, and secondly, the vitiating of the air intended for the gaseous combustibles by depriving it of its due proportion of oxygen?

For what is this increased action of the carbon on the grate but increased combustion? And what is this but an increased absorption of oxygen, the very oxygen that had been intended for another purpose? This cannot be denied, neither will it, that the direct result is to vitiate the *quality* of the hundred measures of air thus sent by an improper route to the gaseous constituents of the coal."

Let us suppose another case, that of laboratory practice, that of ascertaining the largest quantity of carbonic acid and water that could be produced from any given quantity of coal gas and air; for this is, in fact, what we wish to effect in the furnace.

After adjusting our apparatus and measuring the proportion of gas to be operated on, and the air to be mixed with it, suppose that we should discover that the latter, instead of being pure atmospheric air, had been the product of some previous experiment or operation, in which it had been mixed with ignited carbon. What would the veriest tyro in the laboratory say? Would he not reject the whole as unsatisfactory, and begin again, requiring the air to be brought from an unvitiated source?

Yet this is our daily practice. We bring air to the gases which has been employed before in a separate and even destructive process, and yet expect the result to be satisfactory and the combustion complete.

ON THE ASSOCIATION OF ATOMS REQUIRED FOR COMPLETE COMBUSTION.

We have seen that the quantity of air admitted to the furnace determines the proportionate quantity of fuel which may be rendered available for the production of heat. We are now to consider a still more important question, namely, the *degree of mixture* which is required between the substances termed combustible and the supporter of combustion.

There seems to be an established opinion among practical men that, if there be a strong draft and an abundant supply of air, nature will complete the process. A closer examination of this subject will show

that this operation involves a physical impossibility. It has been shown that chemical action will take place only between atoms of different substances removed from each other at insensible distances. If sal ammoniac and lime require to be ground together in a mortar, to bring the atoms of each within the sphere of chemical attraction, how can we expect hydrogen and oxygen to unite without such a mixture of their respective atoms?

Dr. Ure, in his "Chemical Dictionary," informs us that gunpowder is composed of given weights of nitre, charcoal, and sulphur, intimately blended by long pounding in wooden mortars, and that the variations of its strength are occasioned by the relative fineness of division and intimate mixture of the ingredients. Nitre does not detonate unless it comes in contact with an inflammable substance; hence, the whole operation will be more speedy, the more numerous the surfaces of contact; and this surface contact will, of course, depend on the intimacy of the blending. We shall find that a proper mixture of the respective atoms, as a preparation for the complete union and combustion of the elements employed in the combustion of fuel, is just as important as in the case of gunpowder.

In some of our large furnaces more than five hundred pounds of coal are consumed per hour, which would require the mingling of twenty-five hundred feet of coal gas per hour with twenty-five thousand feet of air in a single hour; and this is to be accomplished for the combustion of only the volatile portion of the coal, and under many opposing influences. So numerous are these counteracting influences that we may note only a few of the most important.

1st. The bodies to be mingled are partly solid and partly gaseous.

2d. The gases evolved are heterogeneous, being partly combustible and partly incombustible, and partly supporters of combustion.

3d. The air which has passed over the incandescent fuel is mingled with a large quantity of carbonic acid, which has a much greater specific gravity than the other gases.

4th. The air which has passed over the burning mass has necessarily lost a portion of its oxygen, and consequently the air required to supply the proper amount of oxygen is increased, which will render a proper incorporation more difficult.

These and many other circumstances seriously impede the process of distribution, so that we shall find it utterly impossible to bring about such a degree of incorporation as will enable the atoms of the combustible gases to meet their respective portions of oxygen, and duly arrange themselves for chemical union, before the whole is carried, by the force of the ascending current, beyond the temperature required for ignition, without which any subsequent mixture would be useless.

Some portions of the combustible matter do come in contact with the air, and burn; but we have yet to learn how much larger is the quantity which is carried away uncombined with the oxygen than that which is consumed, and how much the heating effect of what has been consumed has been diminished.

As this branch of our subject is of the utmost importance in a practical point of view, it demands consideration and illustration more in detail.

1st. We will examine the degree of mixture absolutely required for the combustion of coal gas.

2d. What influences, or forces, can we depend upon to effect this intimate incorporation?

3d. Are these influences sufficient to overcome all the impediments met in the present arrangements of our furnaces?

We commence by assuming that all chemical action or chemical union requires the atoms of matter to be brought into the closest possible contact by mechanical mixture, and that the atoms of all gaseous bodies are endowed with the power of moving about among themselves with the utmost facility in all directions.

Now, if chemical affinity is capable of uniting bodies only by atoms, and if these must be in the closest possible relation, what must be the arrangement of the respective atoms of hydrogen and oxygen previous to their ignition? See diagram 4, page [illegible].

As one atom of oxygen always unites with one of hydrogen, and as these atoms unite only when in the closest contact, it follows that the countless atoms composing the mass of oxygen and hydrogen must have been in the closest contact, or have been arranged in sets and pairs, as shown in the diagrams.

Diffusion of Gases. Having shown the degree of mechanical mixture necessary for the chemical union of the coal gas and the oxygen of the air, let us now examine the influences, or force, on which we depend to effect this mixture.

The law which controls the motion of gaseous bodies is different from that which governs the motion of liquids.

Oil and water in the same vessel do not unite. The water, by reason of its greater specific gravity, falls to the bottom of the vessel, while the oil rises to the top.

Every aeriform body, on the contrary, possesses the power of diffusing itself throughout every other aeriform body with which it is brought in contact, in opposition to the force of gravity, until they are so perfectly incorporated that the proportion of any one of the gases in a fractional part of the mixture, will be the same as the proportion of that gas in the entire mixture, or that all parts of the same volume are composed of the same proportions of the gases employed.

Slow Rate of Diffusion of Gases. The rate of diffusion of gases has been made the subject of careful experiment and calculation. In one of our standard works of Physics, we find the following: "When different gases are brought together, they mingle with each other gradually, offering no other resistance to the mixture than the opposition which pebbles present to the motion of the water." Here we have the advantage of small quantities, definite proportions, and deliberate mixture of the masses to begin with, yet we find that the operation is a gradual one. A well-known work on chemical manipulations directs that the oxygen shall be well mingled with the hydrogen, and that they be permitted to remain for a considerable time before firing. Here are deliberate and pains-taking measures for securing a perfect incorporation of the gases, when only a vial is to be used.

In another work we are told that in making mixtures of the gases, although they will appear uniform if sufficient time is allowed, yet "this period will be very long, extending over several hours when the vessels are narrow; even in a wide jar, several minutes are necessary for the complete mingling."

Law of Diffusion. While time will accomplish complete diffusion, yet the effect of varying densities, or specific gravities, in the gases is of sufficient importance to receive our notice. It has been found that the rapidity of diffusion is dependent on the relative densities of the gases, and it appears that the velocities with which gases diffuse themselves are in inverse ratio to the square root of their specific gravities. The following table gives the specific gravities of the several gases met in the furnace, the square roots of their densities, and the reciprocals of these roots, or their rates of diffusion.

Impediments to the Required Association. Here are no less than seven different kinds of gases, all of which come in contact with each other in the furnace, struggling together, yet all tending, according to the law of diffusion, toward perfect incorporation. These bodies, as we have seen, vary in specific gravity, from hydrogen, which is the lightest of all known substances, to carbonic acid gas, one of the heaviest of gases. This is one of the most important natural impediments to the formation of that perfectly uniform mass, which is essential to complete combustion. The most abundant of any of the gases found in the furnace are atmospheric air and carburetted hydrogen. In following table we see that the air has nearly twice the density of carburetted hydrogen, with which it is to mingle, one hundred cubic inches of the carburetted hydrogen weighing only seventeen grains, while the same volume of air weighs thirty-one grains; the contrast is still greater between air and hydrogen, the air being nearly fifteen times heavier than the hydrogen.

RECAPITULATION.

The coke which remains after the volatile constituents have been expelled constitutes from 50 to 80 per cent of bituminous coal.

If coke be brought in contact with a due supply of air, it burns without flame, evolving an intense heat, and producing carbonic acid gas.

The complete combustion of the coke from a ton of coal requires about *two hundred and forty thousand cubic feet of air.*

If there be a deficiency in the supply of the air, the atoms of carbon will unite with one instead of two equivalents of oxygen, and carbonic oxide, instead of carbonic acid, will be produced.

Carbonic oxide is an invisible, inflammable gas, lighter than common air. It is carbon half burned. If brought in contact with a due supply of air, it burns with a pale blue flame, evolving heat, and producing carbonic acid. If no air be supplied, it readily escapes unconsumed, on account of its levity. This is a source of great waste in the use of coke, anthracite coal, and charcoal.

Carbonic acid, generated in the lower portion of the fire-chamber, is converted into carbonic oxide, and passes up through the red-hot embers.

One volume of carbonic acid produces two volumes of carbonic oxide.

In the conversion of carbonic acid into carbonic oxide a large amount of heat is absorbed, and, unless the carbonic acid find a *supply of air*, and be consumed, *it will occasion a serious loss of heat.*

If the air admitted to the furnace has been deteriorated by the loss of a part of its oxygen or contaminated by carbonic acid, it cannot effect the perfect combustion of either the gaseous or the solid portion of the fuel. See the following diagrams, pages 70 to 91.

ELEMENTS WHICH ARE EXPECTED TO BECOME THOROUGHLY INCORPORATED IN THE FURNACE.

NAMES OF GASES.	Sp. Gravity.	Sq. R. of Sp. Gravity.	Rate of Diffusion.
Hydrogen,	.06926	.02632	3.7994
Oxygen,	1.1056	1.0515	.9510
Nitrogen,	.9713	.9856	1.0147
Carburetted Hydrogen,	.559	.7476	1.3375
Bi-carburetted Hydrogen,	.978	.9889	1.0112
Carbonic Oxide,	.9678	.9837	1.0165
Carbonic Acid,	1.52901	1.2365	.8087

Explanation of Diagrams, Illustrating the Laws of Chemical Combinations.

EXPLANATION OF DIAGRAM 1

Use of Diagrams. Since many important elements and compounds found in nature are invisible, a clear conception of their existence, properties, and relations is rendered somewhat difficult. But whenever such invisible substances possess qualities, fixed and clearly defined, which are capable of being represented to the eye, diagrams prove a very efficient means of conveying distinct impressions of them to the mind. By the use of these diagrams, we are able to bring before the eye the more important properties of the elements, the structure of the compound bodies, and the numerical laws of quantity, which govern, with unerring accuracy, all chemical combinations.

The illustrations here given are limited to those elements and compounds which are employed in the *combustion of fuel.*

In diagram 1 the names of the elements are given in the *left-hand column.* Opposite each name is a colored circle, designed to represent the elements. The color given to each circle illustrates one or more properties peculiar to each element. Thus oxygen is the grand agent for carrying on the process of combustion; and, as *red* is the most common representative of fire, we assign this color to all the circles standing for oxygen.

All those varieties of fuel which contain any considerable proportion of hydrogen burn with a yellowish flame, as wood, bituminous coal, etc.; hence this element is appropriately represented by *yellow circles.*

Nitrogen constitutes four fifths of the atmosphere, which, when seen in large quantities, appears *blue;* therefore this color is given to the circles representing nitrogen.

Carbon is shown by *black circles.* This is its natural color as seen in graphite (improperly called black lead) and in the different coals.

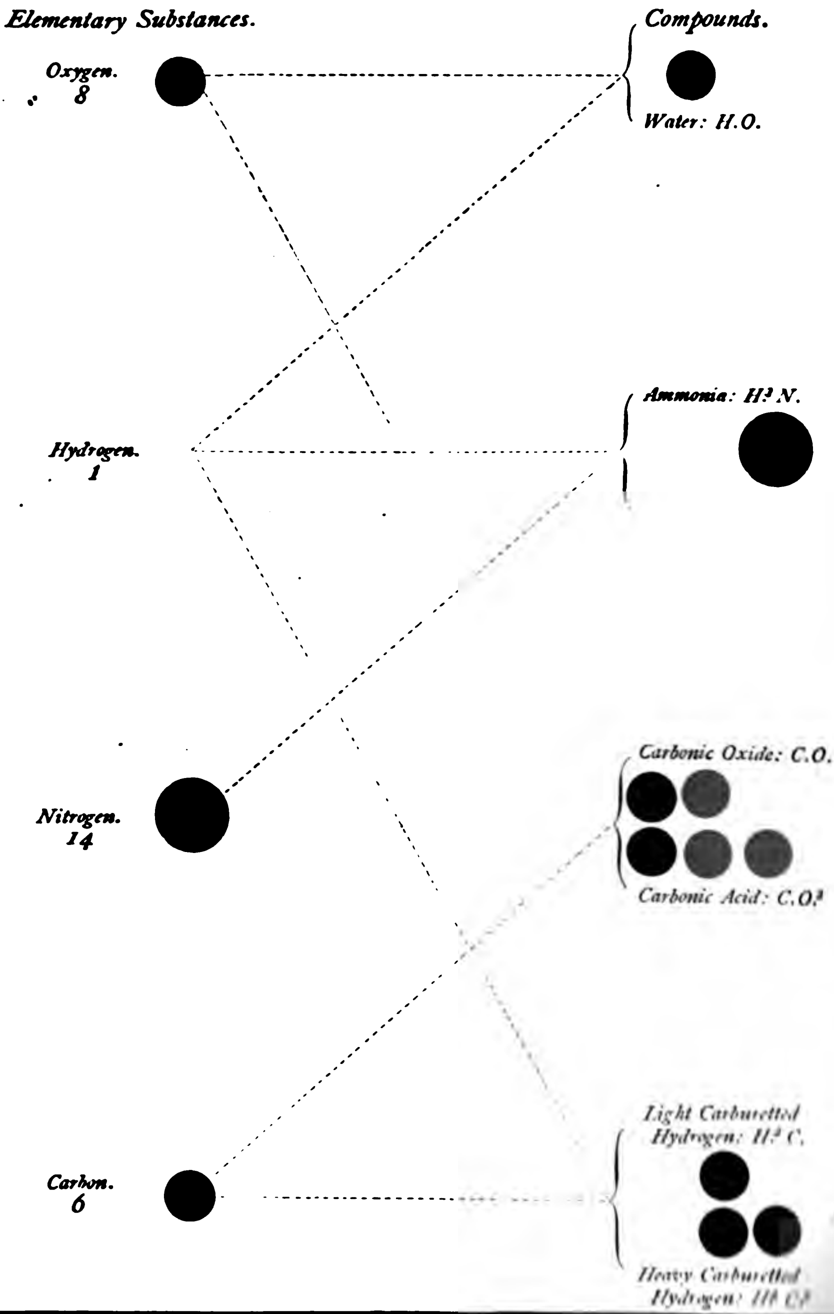
Manner in Which Different Substances Enter Into Chemical Union. *In diagram* 1 the colored circles on the right represent compounds formed from elements on the left.

The lines passing from single circles on the left and conv
the right indicate chemical affinity. See also pages 31, 32,

All the diagrams in this treatise, with the exce
resent the relations and combinations of the diffe
instead of by weight; but hydrogen will still be

DIAGRAM I.

Elements employed and compounds formed in the process of Combustion.



EXPLANATION OF DIAGRAM 2.

Figure 1, on the left, represents the constituent elements of a single atom of carburetted hydrogen, thus:—

1 atom of carburetted hydrogen, —a chemical compound of	1 atom of carbon,	both combustible.
	2 atoms of hydrogen,	
1 atom of atmospheric air, —a mechanical mixture of	1 atom of oxygen,	a supporter of combustion.
	2 atoms of nitrogen,	neither combustible nor a supporter of combustion.

Four atoms of atmospheric air contain four atoms of oxygen and eight of nitrogen; there is, then, an aggregate of fifteen elementary atoms employed in the combustion of a single atom of carburetted hydrogen.

In figure 2, the second column, may be seen the elements composing the atom of carburetted hydrogen in a state of chemical union, condensed to two thirds of their original bulk.

Figure 3 represents the atoms of the compound gas and air brought within the limit of chemical attraction. On the application of the required degree of heat, chemical action begins, and a complete change takes place. The carbon and the hydrogen are now in a state of chemical union. The one atom of carbon and two of hydrogen are held together by chemical attraction. When heat is applied, the attraction between the hydrogen and the oxygen becomes greater than between the hydrogen and the carbon; therefore the elements are separated, and the atoms of hydrogen and oxygen rush together. The carbon is now set free at a high temperature, and unites with the two remaining atoms of oxygen, to produce carbonic acid.

Figure 4 represents the first stage of the process, on the breaking up of the compound gas, when each of the elements attaches to itself its own equivalent of oxygen. The nitrogen, on account of its "neutrality," has taken no part in the process, and is left unattached; and we see that the atom of carbon and each of the two atoms of hydrogen are supplied with the exact proportion of oxygen required for their chemical union.

Figure 5 shows the product of these unions:—

One atom of carbonic acid, formed by the union of the atom of carbon with its equivalent of oxygen, and condensed into two thirds the space occupied by its elements.

The two atoms of steam, each formed by the union of one atom of hydrogen and one of oxygen, and condensed into two thirds the volume of its elements.

DIAGRAM 2—(CONTINUED.)

Explanation of diagram 2 will also help the reader to comprehend the several changes which occur during the complicated process of combustion. It will also help him to grasp and fix both the relations as to quantities, between the several bodies which enter into chemical union, and the compounds which such bodies relatively produce during this process.

The first impression on inspecting the diagram is the large volume of air required for the combustion of so small a volume of coal gas. But when we take into consideration the preponderating quantity of nitrogen which is present, the reason of this is obvious. This, however, is unavoidable so long as we depend on atmospheric air for our supply of oxygen. If it be true (and no scientific truth is more firmly established) that elements will combine only in the proportions here represented, we can readily comprehend the loss resulting from a deficiency of either.

Directly below are represented the constituents of air in their combined state; but, since this is only a mechanical mixture, there is no diminution in bulk. It has been shown that chemical union can take place only between substances which are removed at insensible distances from each other.

Therefore these atoms must be brought in contact previous to combustion.

The elements which compose the atmosphere have the same volume when taken separately as when united; whereas the elements of steam, carburetted hydrogen, carbonic acid, and many other compounds, are condensed on entering into chemical union; but we must bear in mind that these are chemical compounds, while the atmosphere is only a mechanical mixture of its elements.

No one can look for a minute at these illustrations without noticing the very large volume of nitrogen which must pass through the furnace, and what an almost insurmountable difficulty the presence of this element offers to that degree of incorporation which perfect combustion requires.

Note. It must be remembered that the colored circles show the *relative volume*, or *bulk*, of the corresponding atoms, while their relative *weights* are indicated by the numerals placed just below the name of each, at the bottom of the page. The relative volumes of carbon and hydrogen in any one atom of carburetted hydrogen show their relative volumes in any larger quantity, as each atom of the compound gas has exactly the same composition. See pages 58 and 59.

Representing the Chemical Union and

and A

Fig. 1.

Constituent Elements of Carburetted Hydrogen and Atmospheric Air.

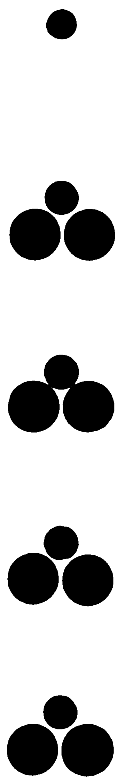
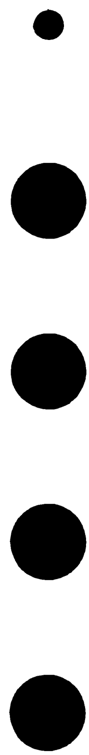


Fig. 2.

Single Atoms of Air and Carburetted Hydrogen, being compounds of the Constituents as in the preceding column.



Requi... in the prec... to their Ch... bustion on ...

Explanation of the Symbols in the ...

of an Atom of Carburetted Hydrogen
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Atoms
ratory
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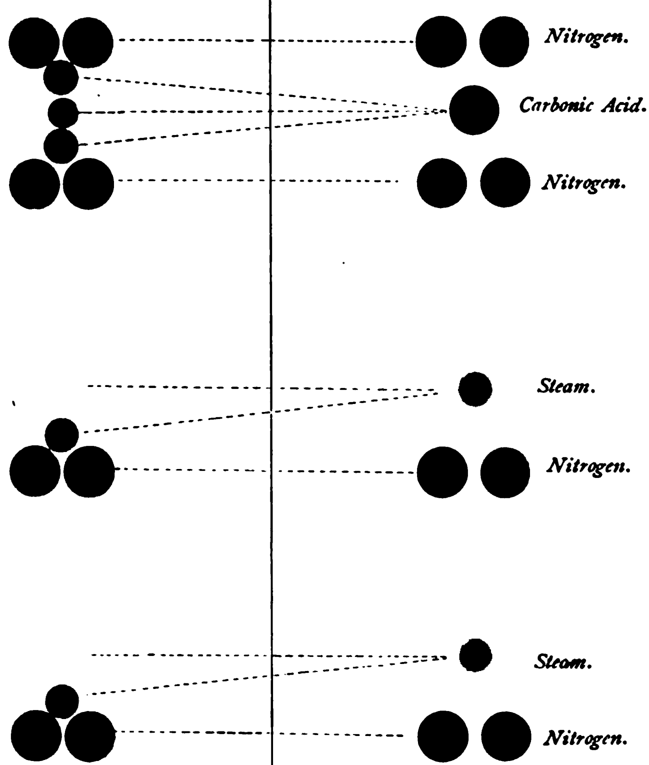
Fig. 4.

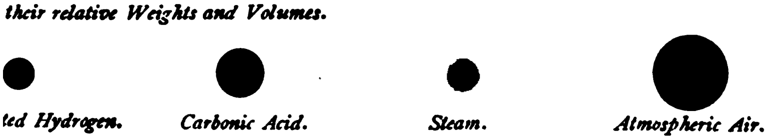
State of Decomposition of Carburetted Hydrogen preparatory to the Chemical Union of the Constituents with their respective Equivalents of Oxygen.

Fig. 5.

Products of the Combustion of one Atom of Carburetted Hydrogen with its equivalent of Atmospheric Air.



their relative Weights and Volumes.



Explanation of Diagram 3.

Figure 1 represents an atom of carbonic *acid*, with its constituent elements—two atoms of oxygen and one of carbon—at the left.

Figure 2 represents an atom of *carbonic oxide*, with its constituent elements—one atom of *oxygen* and one of *carbon*.

This *carbonic oxide* is a transparent, colorless gas.

When inhaled, it is exceedingly injurious to the respiratory organs. Air which contains only one part in a hundred of this gas is said to be fatal when inhaled for any considerable length of time. In close, heated rooms, where coal is used for fuel, deaths are often caused by closing the escape pipe, or leaving the stove door open and allowing the gas to escape into the room. This fatal effect is usually attributed to carbonic acid; but this poisonous gas not infrequently enters the room mingled with *carbonic oxide*, a gas still more deadly in its effects.

The cause of the formation of such a compound is of interest here. It cannot be the result of *complete* combustion of carbon; for, as has been shown, *carbonic acid* is the only product of that process. The mode by which this gas is sometimes obtained in the laboratory for experiments will give an insight as to the mode of its formation in the furnace. If we take an iron or porcelain tube, place in it fragments of charcoal, heat it to redness, and then pass a stream of carbonic acid over the heated coals, the carbonic acid will lose one half its oxygen and be converted into carbonic oxide. The oxygen which has been given off will unite with the heated coal, and form another volume of carbonic oxide.

A similar action takes place in the furnace. If the supply of oxygen be sufficient, carbonic acid will be formed.

If carbonic acid is produced and brought in contact with heated carbon, with *no free* oxygen, the carbonic acid will lose half its oxygen, and become carbonic *oxide*. The liberated oxygen will unite with the heated carbon and furnish an equal volume of the same gas.

Figure 3 in diagram 3 shows one atom of *carbonic acid*, and the volume of its constituents. When an atom of carbonic acid is brought in contact with heated carbon, one of the atoms leaves the carbonic acid, and this acid becomes *carbonic oxide*. At the same time the atom of disengaged oxygen unites with an atom of carbon, and forms another atom of carbonic oxide of the same volume as the first.

It must be remembered that the colored circles show the relative volume or bulk of the respective atoms, while their relative weights are indicated by the numerals placed just below the name of each, at the bottom of the page. (See diagram 2.)

DIAGRAM 3.

Showing how Carbonic Acid is converted into Carbonic Oxide.

Fig. 1.

Constituent Elements of Carbonic Acid and their Volume after Chemical Union.

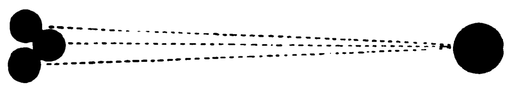


Fig. 2.

Constituent Elements of Carbonic Oxide and their Volume after Chemical Union.

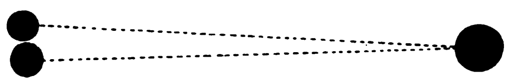


Fig. 3.

Constituent Elements of Carbonic Acid and their Volume after Chemical Union.

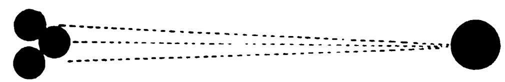
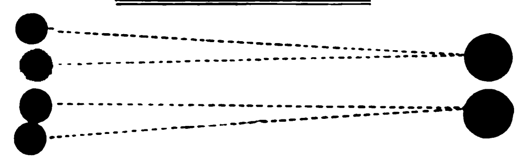


Fig. 4.

Two Atoms of Carbonic Oxide which have been formed from One Atom of Carbonic Acid by the addition of one Atom of Carbon.



Explanation of Diagram 4.

Illustrating the Combustion of a Given Volume of Hydrogen and Its Equivalent of Oxygen. As one atom of oxygen always unites with one of hydrogen, and as these atoms unite only when in close contact, it follows that the countless atoms composing the mass of the oxygen and hydrogen must have been arranged in sets or pairs as shown.

Figure 1 represents a section of a body of hydrogen and a section of a body of oxygen required for its complete combustion. The different sizes of the circles show the relative volume, or bulk, of any two atoms of these gases.

Let us suppose that the red circles representing the oxygen in figure 1 be moved toward the yellow circles representing the hydrogen, until the upper row of the red comes in contact with the lower row of the yellow circles.

Now, on applying the proper degree of heat required to induce chemical action, how many of these atoms will unite?

Clearly, only those which are in contact, for chemical affinity acts only on bodies which are at immeasurably small distances from each other; hence only eight of the thirty-two atoms will enter into combination, and three fourths of the heat which might have been evolved, would be lost.

Before complete combustion can take place, every one of the atoms of hydrogen must find, and be brought within the attractive influence of its own atom of oxygen.

Figure 2 represents such an arrangement of the respective atoms, and figure 3 represents the product of the several combinations—sixteen atoms of steam.

In this case we notice that not an atom of hydrogen or oxygen escapes uncombined. Consequently we have the maximum amount of heat which can be developed from the given amount of hydrogen. This gives us a clear idea of the degree of mixture or association of atoms which nature requires for perfect combustion, so far as hydrogen and pure oxygen are concerned. It is not claimed that we know, or ever can know, the actual form of an atom of matter, or the precise manner in which the several atoms arrange themselves; but this is certain, that a given bulk of hydrogen will combine with only half its bulk of oxygen, and that this union will take place only as they are thoroughly blended.

The immediate union of hydrogen with oxygen only occurs at a high temperature, either in contact with a flame or by an electric spark.

Water is the product of the combustion of hydrogen and oxygen.

DIAGRAM 4.

Representing the Combustion of a given Volume of Hydrogen and its equivalent of Oxygen.

Fig. 1.

Hydrogen to be consumed and its equivalent of Oxygen.

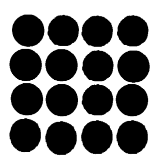


Fig. 2.

Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union.

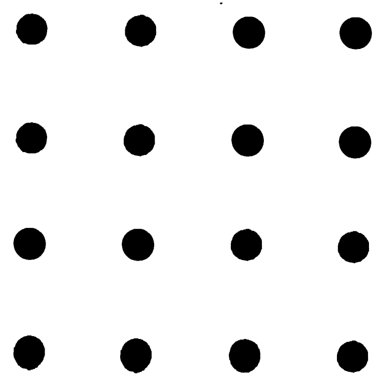
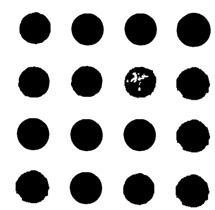


Fig. 3.

Products of the Combustion of a given Volume of Hydrogen and the equivalent of Oxygen.

Steam.



Explanation of Diagram 5.

Illustrating the combustion of a given volume of carbon.

Figure 1, diagram 5, represents the carbon and the volume of the oxygen required for its combustion.

Figure 2 shows the association of the atoms required previous to ignition; and

Figure 3 the resulting product, carbonic acid, being two thirds the original bulk of the mixture.

For the perfect combustion of the carbon, each atom must unite with two atoms, or double its bulk of oxygen.

This gives us an idea of the *perfect combustion* of a given volume of carbon. The proportions between the oxygen and the carbon are so definite, and the diffusion of the respective atoms among themselves is so complete, that each atom is within the sphere of chemical attraction before being fired, so that not a single atom of either element escapes combination.

Chemical and Physical Properties of Carbon. Carbon is one of the most widely diffused of the elements. It occurs in a free state in the diamond, as graphite, and as charcoal; these three varieties constitute modifications of the element. No better example of the striking differences which it is possible to effect in the appearance of a substance by variety of atomic arrangement, could be adduced than that of carbon.

Carbon also exists in nature in combination with oxygen, forming carbon dioxide, a gas which is present in a free state in the air, and which is largely evolved from subterranean sources.

A large proportion of the solid crust of the earth is made up of compounds of carbon dioxide with various bases, entire mountain chains being composed of the carbonates of calcium and magnesium. Immense areas of calcium carbonate, brought together by the vital processes of minute organisms, exist beneath the sea's surface.

All organic matter contains carbon in combination with hydrogen, oxygen, and nitrogen, etc. Indeed, this element is specially characteristic of animal and vegetable life; every organism contains it. Its combinations with hydrogen are particularly numerous.

The petroleum oils, naphtha, marsh gas, benzine, illuminating gas, etc., are all hydrocarbons, that is, compounds of carbon and hydrogen.

DIAGRAM 5.

Representing the Combustion of a given Volume of Carbon and its equivalent of Oxygen.

Fig. 1.

Carbon to be consumed and its equivalent of Oxygen.

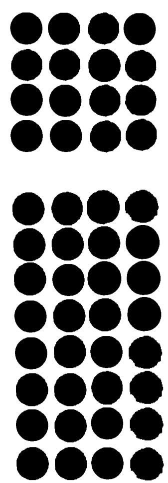


Fig. 2.

Required Mixtures of the Atoms in preceding column preparatory to their Chemical Union.

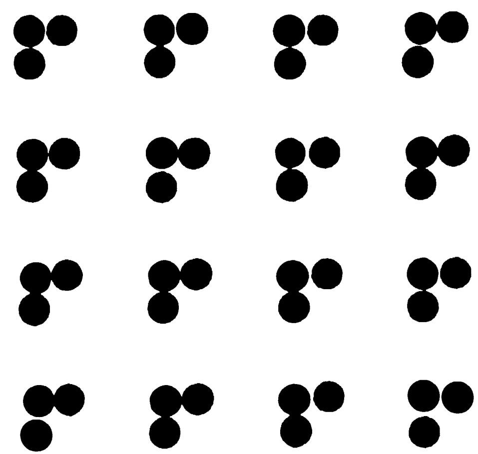
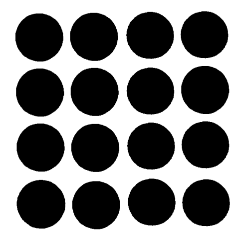


Fig. 3.

Products of the combustion of a given Volume of Carbon and its equivalent of Oxygen.

Carbonic Acid.



Explanation of Diagram 6.

The Combustion of a Given Volume of Carburetted Hydrogen. Diagram 6 represents the required mixture and combustion of a given volume of *carburetted hydrogen, with its equivalent of oxygen. Figure* 1 represents the volume of carburetted hydrogen to be consumed, and the volume of oxygen required for its combustion. *Figure* 2 *and figure* 3, the products of combustion — carbonic acid and steam. It will be remembered that carburetted hydrogen is composed of two equivalents of hydrogen and one of carbon, and that each equivalent of hydrogen requires for its combustion one equivalent of oxygen, and that one equivalent of carbon requires two of oxygen; hence one equivalent of carburetted hydrogen requires four equivalents of oxygen, and the sixteen equivalents of carburetted hydrogen sixty-four of oxygen, as shown in the diagram.

It was stated, in the case of the burning candle, that the oxygen first seizes on the *hydrogen*. When the atoms are arranged as in *figure* 2, two atoms of the oxygen seize on the hydrogen of the compound gas, and produce two atoms of steam, as shown in *figure* 3. This sets the carbon free, and soon it unites with the other two atoms of oxygen, and produces one atom of carbonic acid. When we can conceive of these changes happening to every one of the countless millions of atoms, of which even a very small quantity of coal gas is composed, we shall have some just conception of what is constantly taking place in the combustion of fuel. This degree of incorporation of the elements may seem very difficult, even impossible, in the case of a furnace, *yet no fact is plainer than that on this depends the amount of heat generated.*

If we were obliged to mix thoroughly one bushel of wheat with two bushels of rye, previous to grinding, we should find our task rendered much more difficult if we were obliged to take the wheat with four times its bulk of chaff.

Yet it is precisely in this proportion that the oxygen enters the furnace mingled with nitrogen, which is worse than useless so far as aiding the combustion is concerned.

But if the perfect mixture seems difficult in the cases referred to, what shall we say when the oxygen enters the furnace diluted with four times its bulk of the inert element, nitrogen, a substance totally deficient in power to support combustion. The presence of so large a volume of this neutral element will lessen by four times the chances for perfect incorporation, and, in addition to this, will absorb and carry away a very large quantity of heat.

DIAGRAM 6.

Representing the Combustion of a given Volume of Carburetted Hydrogen and its equivalent of Oxygen.

Fig. 1

Volume of Carburetted Hydrogen to be consumed and its equivalent of Oxygen.

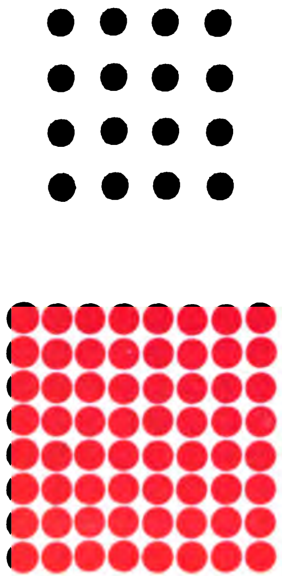


Fig. 2.

Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union.

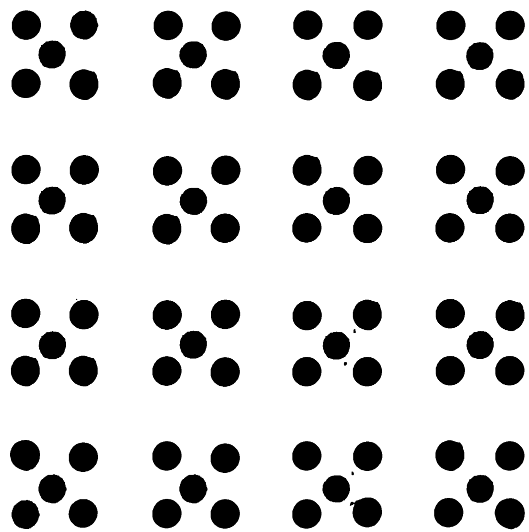
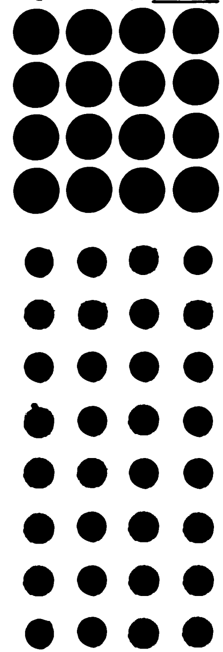


Fig. 3.

Products of the Combustion of a given Volume of Carburetted Hydrogen and its equivalent of Oxygen.



Carbonic Acid.

Steam.

H. CHANDLER, SC. BUFFALO.

EXPLANATION OF DIAGRAM 7.

Diagram 7 represents a volume of hydrogen with its equivalent volume of air, the mixture required previous to combustion, and the resulting products — steam and free nitrogen. Figure 1 shows the volume of hydrogen to be consumed, and also the required volume of air. Figure 2 represents the mixture previous to combustion; and figure 3 the volume of steam and free nitrogen which passes away.

Chemical and Physical Properties of Hydrogen. Hydrogen, a gaseous body, occurs only exceptionally in a free condition on the earth's surface, as it combines readily with the oxygen of the air. It is found in considerable quantity in the photosphere of the sun and the fixed stars.

In combination we find it principally as water and in substances of animal and vegetable origin. Paracelsus first discovered the element in the 16th century, and called it inflammable air. In 1781 Watts and Cavendish showed that water resulted from the combustion of hydrogen in the air.

Physical Properties. Hydrogen is a colorless, odorless, and tasteless gas. Its ability to refract light and conduct heat is in accordance with the metallic nature of hydrogen, greater than that of all other gases. By cooling (284° below zero) and powerful pressure (600 atmospheres) it is condensed to a steel blue, non-transparent liquid, which upon further cooling by evaporation even becomes solid; consequently liquid hydrogen resembles a molten metal, or, at ordinary temperatures, liquid mercury. It is the lightest of all gases, being 14.46 times lighter than air. Its specific gravity, compared with air as unity, is 0.06926.

Chemical Properties. Hydrogen is characterized by its ability to burn in air, at the same time combining with the oxygen of the latter and forming water; hence its name, signifying producer of water. Its flame is faint blue, and almost non-luminous. As hydrogen itself is inflammable, it cannot sustain the combustion of other bodies which will burn in air.

If a burning candle be introduced into an atmosphere of the gas contained in an inverted cylinder, the latter will ignite at the mouth of the vessel, but the candle is extinguished in the hydrogen gas.

When a mixture of hydrogen and air is ignited, a violent explosion ensues. Water is the product of the combustion. It is a chemical compound containing hydrogen and oxygen. The immediate union of hydrogen with oxygen only occurs at a high temperature either in contact with flame or by the electric spark.

DIAGRAM V.

Representing the Combustion of a given Volume of Hydrogen and its equivalent of Atmospheric Air.

Fig. 1.

Volume of Hydrogen to be consumed and its equivalent of Atmospheric Air.

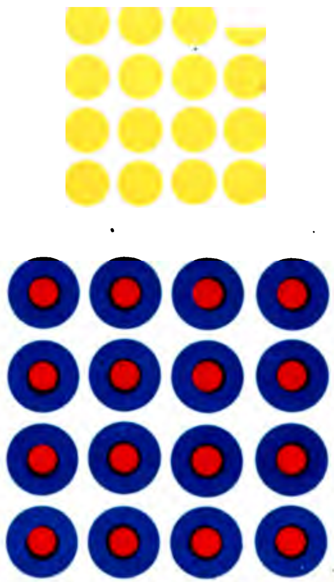


Fig. 2.

Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union.

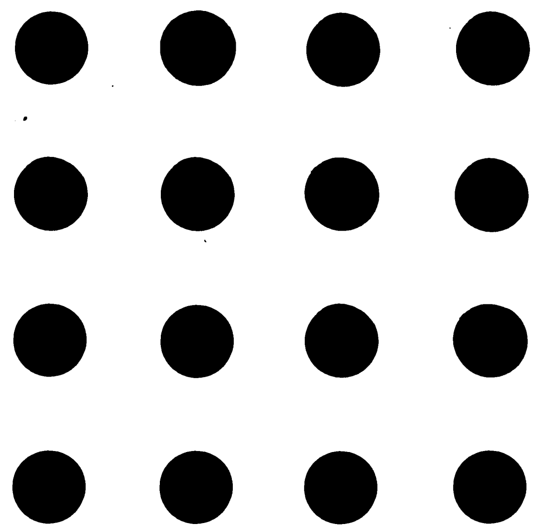


Fig. 3.

Products of the Combustion of a given Volume of Hydrogen and its equivalent of Atmospheric Air.

Explanation of Diagram 8.

Diagram 8 represents the preparatory mixture of the air, and the combustion of a given volume of carbon.

Figure 1 shows the carbon to be consumed, and also the volume of the air required for its complete combustion;

Figure 2 the required mixture of the elements; and

Figure 3 the resulting products, carbonic acid and free nitrogen.

Note. Not requiring the entire space of this page for explanation of diagrams, it seems proper to state that in Dimond's arrangement the diagrams were not together, but with the text, and considerably isolated, while the back of each plate was blank (a clear loss of good material and opportunity).

Besides, the matter here presented is less than one half of the original text, considerable space being devoted in Dimond's treatise to the production and preparation of peat fuel for the market, and to various experiments in chemistry requiring his drawings to illustrate, chiefly of value to the chemist or student.

While the leading thought with Dimond was the simple and graphic illustration of the combustion of solid fuel, and mainly the bituminous variety, yet this very fact — the gaseous nature of the fuel — renders these diagrams of the chemical combinations *by volume* of the gaseous fuel and the *supporter of combustion, oxygen,* at once the key to the proper burning of every fuel, — solid, liquid, and gaseous, that have either carbon or hydrogen in their composition, — and thus the diagrams may be consulted for the proper combination and burning of coal, oil, natural and manufactured gases.

A perusal of the following chapter on the discovery of the oils, and their accompanying natural gases, and the late application of them to nearly all the industries requiring pure and concentrated heat, shows:—

1st. The great changes in our heat-producing mediums and methods, and that, whatever the supply of coal, its use in a *solid* state will be restricted to the hard or anthracite variety and to limited locations.

2d. That a liquid or gaseous fuel is, and must of necessity be, the "*fuel of the future,*" not only to large industrial operations, but for domestic use as well. To this particular matter we will refer later.

DIAGRAM 8.

Representing the Combustion of a given Volume of Carbon and its equivalent of Atmospheric Air.

Volume of Carbon to be consumed and its equivalent of Atmospheric Air.

Fig. 1.

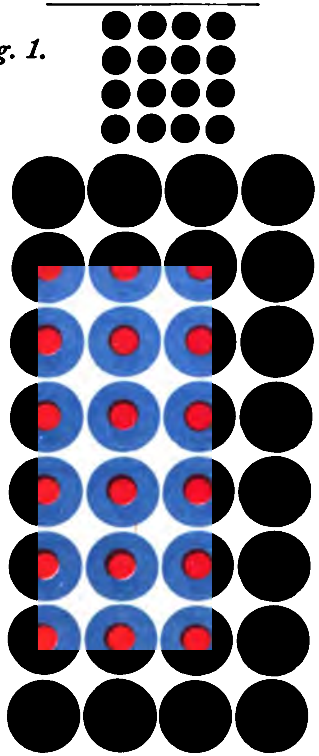


Fig. 2.

Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union.

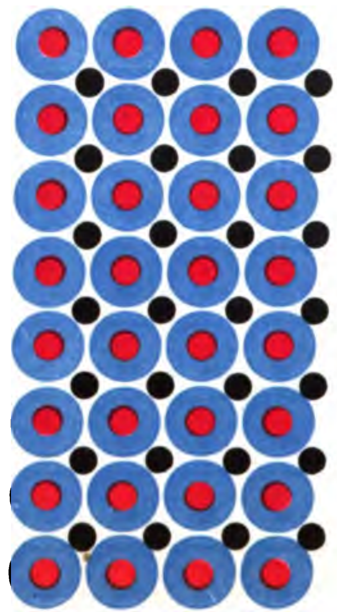
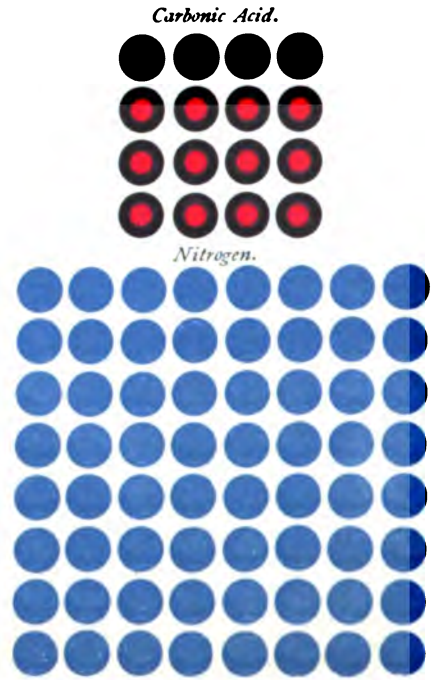


Fig. 3.

Products of the Combustion of a given Volume of Carbon and Atmospheric Air.



EXPLANATION OF DIAGRAM 9.

Carburetted Hydrogen. Figure 1 represents a volume of carburetted hydrogen and its equivalent of air. Figure 2 shows the arrangement of atoms before combination, and figure 3 the product of the combustion — *carbonic acid*, *steam*, and *pure nitrogen*. Sixteen atoms of carburetted hydrogen require for their combustion sixty-four atoms of air, and give us, after combustion, sixteen atoms of carbonic acid, thirty-two atoms of steam, and a hundred and twenty atoms of pure nitrogen.

It is not necessary to give diagrams illustrating the combustion of bi-carburetted hydrogen, as the conditions are the same. It will be remembered that the only difference between this and carburetted hydrogen is that the former contains double the amount of carbon for the same amount of hydrogen.

For the complete combustion of carbonic oxide, one atom (one half a volume) of oxygen, or five atoms (two and a half volumes) of air, are required for every atom of the gas, and the same degree of mixture as in the foregoing illustrations.

No one can look for a moment at these illustrations without noticing the very large volume of nitrogen which must pass through the furnace, and what an almost insurmountable difficulty the presence of this element offers to that degree of incorporation which perfect combustion requires.

On this account attempts have been made to obtain the oxygen from other sources than the atmosphere, so that the presence of this neutral element may be avoided; and lamps supplied with oxygen for light-houses and public buildings have been used with success. This method of effecting combustion, however, can never come into general use until some more simple and less expensive method for obtaining pure oxygen is discovered.

Diffusion of Gases. It appears that the law which governs the motion of gaseous bodies is different from that which governs the motion of liquids. Oil and water in the same vessel do not unite. The water, by reason of its greater specific gravity, falls to the bottom of the vessel, while the oil rises to the top. Every aeriform body, on the contrary, possesses the power of diffusing itself throughout every other aeriform body with which it is brought in contact, in opposition to the force of gravity, until they are so perfectly incorporated that the proportion of any one of the gases, in any fractional part of the mixture, will be the same as the proportion of that gas in the entire mixture.

Explanation and Correction of Diagrams.

These first chapters are, as seen, a study of combustion, scientifically and practically considered. This matter is an abridgment of a work by W. E. Dimond, when a Professor of Chemistry at Dartmouth College, N. H. The plates and text were prepared to illustrate that the inventions of Sidney Smith were based on sound philosophy and correct science, and that *chemistry* was the key to this, and to all proper construction in steam boilers and other furnaces.

The plates of this work were, however, destroyed in the great fire at Boston in 1872. They are now (by the kind permission of Mr. Smith) reproduced under the conviction that, although the idea was not new, Dimond's treatment of combustion and chemical union by *form*, *size*, *color*, and *proportion* is the best illustration that this beautiful and exact science has received at the hands of any writer, and that, in reviving this lost work, *the author pays his tribute to its signal worth*, *while restoring it to the public, for whom it was originally intended.*

The diagrams illustrating the various elements and their combinations are reproduced by photographic transfer, and then engraved in wax by the relief-line process. They are doubtless correct in all essential particulars, although the careful student in modern chemistry will perhaps note some differences in expression or what may be called *chemical notation.* For instance, in diagram 1, page 71, water may be seen represented by H O instead of H_2 O, as expressed in later chemical works, signifying that water is composed of *two* parts or atoms of *hydrogen* to *one* of *oxygen.* This is correct when estimating the atoms by number, so the expression of H O is doubtless correct when estimating these elements by weight instead of by atoms.

Where hydrogen is unity or one, oxygen will be eight; or, if hydrogen were represented by two atoms, oxygen would be sixteen. In this view both the new and the old methods of expressing combination by volume are the same. See pages 31, 32, 33.

* NOTE.— It should be remembered that the colored circles show the relative volume or bulk of the corresponding atoms, while their relative weights should be indicated by numerals placed below the name of each. By a singular error of the engraver and the proof-reader these numerals were omitted. They are as follows:—

Oxygen (8), **Carbon** (6), **Nitrogen** (14), **Hydrogen** (1), **Carburetted Hydrogen** (8), **Carbonic Acid** (22), **Steam** (9), **Atmospheric Air** (36).

For further reference to this method of chemical notation, see Youman's *Atlas of Chemistry*; also his *Class Book of Chemistry*, H. S. King & Co., London.

* Diagram No. 2, figure 6, bottom of pages 74 and 75.

DI...

Representing the Combustion of a given Vo...
Atm...

Fig. 1.

Volume of Carburetted Hydrogen to be consumed and its equivalent of Atmospheric Air.

F...

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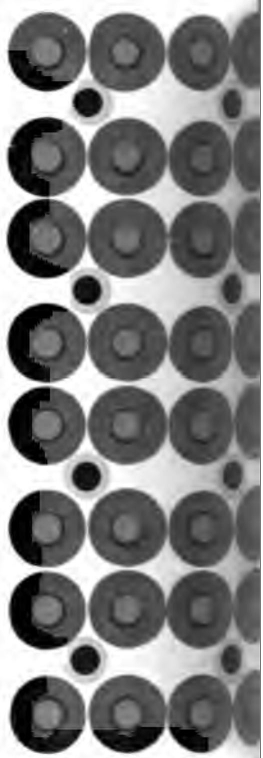

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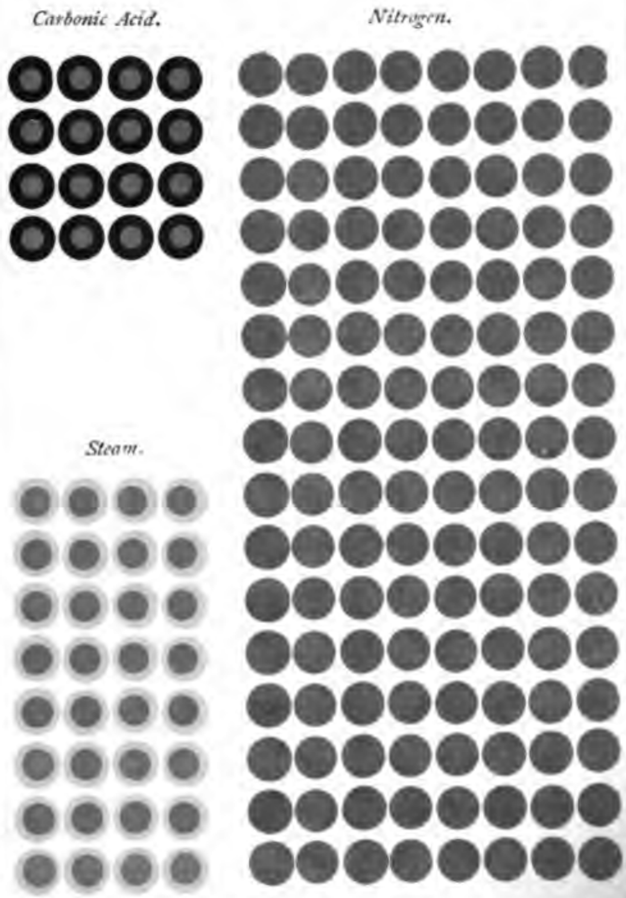
Fig. 3.

Products of the Combustion of a given Volume of Carburetted Hydrogen and its equivalent of Atmospheric Air.



CONCLUSIONS.

To throw coal on a grate, to pass oil into a furnace, to feed gas into a fire, is the simplest of all mechanical operations, but it is not chemistry, or the intelligent combination of the combustibles with oxygen under such conditions as will secure the greatest heat and economical effect.

That carbon in a fine or powdered condition, or in the form of a liquid, or that of the natural and manufactured gases, is in a much better condition for the intelligent and educated engineer to handle, is true, but it offers no essential advantage to the average fireman or mechanic except a chance to get away with his employer's money — if not to blow him and his dwelling into the air; therefore, my last word to all intending the introduction of oil or gas fuel is, go slow, be sure you are right before you go ahead! The essential conditions have been so fully described and illustrated that we have room for only the following: —

Whenever heat is desired, something must be burned or changed; the burning is termed combustion.

To insure combustion, a combining of the elements must first ensue. On the perfection of this combination or mixture depends the amount and temperature of the heat of the fire.

Carbon, oxygen, and hydrogen are the principal elements to be combined. Carbon is a solid found in wood, coal, coke, peat, also in oil.

The *oxygen* (principally found in common air) and also *hydrogen* are gases, the latter generally liberated during the burning of other combustibles.

Combustion, then, in whatever form, or from whatever materials derived, is a *combining* of certain elements in definite and determined proportions; and the numbers expressing these proportions are called equivalent or combining numbers or atomic weights.

See pages 34 and 35.

Chemistry is the *science* and the *key* to all proper and necessary data for the burning of fuels.

Without a knowledge of this and an application of the truths illustrated in Part I., no man is fitted to construct furnaces. He may have unlimited coal, oil, and gas at his disposal, but he cannot realize their value. They will pass through his fingers like fine gold in the river sands,— nay, he may starve on the bank, while a flask of mercury with which to *recover* the gold would make him a millionaire.

Brains, in a well-constructed head, may stand for our references to the flask of mercury; while ignorance and prejudice, in its place, yield, as they always have, only starvation wages.

CHAPTER VIII

The Construction of Furnaces Adapted to the Proper Combustion of Fuel.

PART SECOND.

HAVING considered in the former part of this treatise the important part which fuel is destined to play in promoting personal comfort, securing wealth and national prosperity, and having pointed out some of the more general properties, both physical and chemical, belonging to different varieties of fuel, and having explained those laws which will prove to be the only correct guide in our efforts to secure the greatest economy in its use, we now propose to make a practical application of these facts and principles to the construction and operation of furnaces.

Scientific Principles our Guide in the Construction of Furnaces. The mechanical engineer will ask "What have these to do with furnace making or furnace working? Your experiments and laws are well enough for the laboratory and class-room; your theories are plausible enough, but we do not care for these. They have nothing to do with the practical working of a furnace. There is just so much heat in a pound of coal or carbon, and you can obtain no more. If the air be admitted to the furnace, nature will do the rest."

It would be well for the objector to bear in mind that the teachings of science and the principles which it enunciates are by no means "theoretical." They are founded on an analysis and comparison of facts, which have been established by the most careful and painstaking experiments.

It is a principle of natural philosophy that two bodies cannot occupy the same space at the same time; but, if any man be so unwise as to suppose that this is merely a theoretical truth, and persist in the attempt to make his head and a brick wall occupy the same space at the same time, he will, after a few well-directed and persevering efforts, become convinced that this principle is a practical truth, and one which applies to his particular case.

The varied mechanical and chemical mutations effected upon matter are governed by laws fixed, clearly defined, and universal in their application. If, then, implicit obedience to nature's laws be indispensable to satisfactory results in the one case, it is equally so in the other.

Therefore a knowledge of the nature and properties of different kinds of fuel, the character of the elements composing the atmosphere, and the laws of chemical combination has everything to do with determining the construction and arrangement of different parts of the furnace. *A knowledge of these involves the whole question of right and wrong, of entire success or partial failure, of economy and waste.*

The Reason that so Many Inventions Prove Unsuccessful. There has been sufficient time, money, and skill expended in originating methods and in perfecting apparatus for economizing the use of fuel, but unfortunately our inventive genius has been groping its way in the dark; consequently much of it has been on the wrong track. Many of the contrivances which of late years have encumbered the patent list have been based on no principle, justified by no proof, while some even are in direct opposition to the laws of nature. The reason for this is obvious. Our inventors in that line have not been men whom early training and correct habits of thought have fitted, and whose business has permitted, to investigate chemical agencies and processes; and they have therefore failed to become masters of the fundamental principles upon which the success of their inventions depend.

What the First Step Should Be. No practical chemist would attempt to decide on the size, shape, and strength of his retort, crucible, or other apparatus without previous consideration of the nature, conditions, and tendencies of the substances with which he is about to operate. Now, combustion is a chemical experiment, and, as such, is one of the most brilliant, interesting, and instructive within the department of chemical science. The furnace is the retort. How, then, can we know how to construct the furnace before we have learned the nature of the process which is to take place?

Combustion Incomplete in an Ordinary Furnace. Keeping in view the numerous and convincing illustrations of what nature requires, as exhibited in the preceding chapters, it is evident that the construction and arrangement of any furnace, which has for its object the combustion of fuel containing volatile hydrocarbons, must be based on the following principles:—

1st. Of furnishing an adequate supply of air.

2d. Of permitting the air to be carried to the fuel in different parts of the fire chamber in a pure state.

3d. Of producing an intimate mixture between the air and the inflammable gases before they have passed beyond the point where the temperature is sufficient to induce chemical action between the combustible and the supporter.

It demands no very close scrutiny or keen observation to discover that a furnace, constructed on the ordinary plan of admitting the air *en masse* through the grate, fails to meet any one of the foregoing conditions. The bars or grate are always, or should be, covered with a mass of incandescent coke.

When a fresh charge of coal is thrown into the furnace, the passage for the air through it must be more or less closed, therefore the supply of air for the time is greatly diminished; but this is the very time when there is the greatest demand for a larger supply of air, for the moment the fresh coal comes in contact with the highly heated coke, it absorbs heat and large quantities of inflammable gases are set free, for the combustion of which a large volume of air is required.

Thus the smallest quantity of air is unavoidably admitted at a time when there is a demand for the largest supply.

This gas, as we have seen, consists mainly of carburetted hydrogen, yet contains a percentage of pure hydrogen, of bi-carburetted hydrogen, and of carbonic oxide, all of which are the best inflammables for the generation of steam.

Not only are these valuable heat-giving commodities lost, but it would have been better had they not existed in the coal, as their production renders latent a large amount of heat, which at times almost paralyzes the effective operation of the furnace.

When a fresh supply of coal is put on a briskly burning fire, the first thing that takes place is that the coal softens and swells, attended with the evolution of a large quantity of carburetted hydrogen gas, requiring for its combustion a correspondingly large supply of atmospheric air, — the coal undergoing, in fact, in the first stage of combustion, just the same process that it does in the retort in the manufacture of gas, which in the latter case is preserved and found so useful as a commodity, but which here escapes unconsumed up the chimney.

It not only furnishes no heat itself, but abstracts from the heat arising from the combustion of the carbonaceous parts of the fuel the heat for its own gasification — a circumstance which readily explains the fact that more heat is practically obtained in many furnaces by means of coke (or in other words coal deprived of about one-third part, by weight, of that portion of its combustible matter which is richest in furnishing material for heat) than from coal in its pure state, with all its hydrogenous portion intact.

From the same cause — viz., *the imperfection of our furnaces* — the commercial value of coal is often in inverse ratio to the quantity of its bituminous constituents, and its real heat-giving powers, had we the capacity to render them available. It cannot, in fact, be otherwise; for a furnace, immediately after a supply of fresh fuel, requires more than double the air it did the instant before, while we have no contrivance for furnishing such a supply; although without it, throughout the time during which gasification of the hydrogenous portions is going on, more than half the fuel consumed is wasted and passes off unburned, becoming thereby, not only totally unproductive in itself, but absolutely an agent of evil, by robbing the furnace of the heat absorbed in its own gasification.

When too limited a supply of air is admitted for the complete combustion of either carburetted or bi-carburetted hydrogen, the hydrogen unites with the oxygen and is converted into water, while the carbon is deposited in the form of smoke or soot; or it may find sufficient oxygen to become converted into carbonic oxide, and partly into carbonic acid.

When carburetted hydrogen is kindled, and just as much oxygen admitted as will consume its hydrogen, the carbon does not burn at all, but is sent off in the form of smoke or deposited in soot.

After the volatile hydrocarbons have been driven off, the supply of air demanded is very much diminished; and, after the body of coke has become thin on the bars, the passages for air may become so large that a great excess is admitted, which retards the rapidity and intensity of chemical action by its cooling effect, and also absorbs heat in passing through the fire chamber, so as to lower the general temperature, and thus prevent the rapid generation of steam.

There is another difficulty in the way of furnishing a due supply of air from below the grate. As the volatile matter is expelled, the process of "coking" commences, and continues until a mass is formed almost impervious to air; so that its passage into the furnace through the grate is in a great measure cut off. The same difficulty is experienced in using coal of a smaller size, shavings, saw-dust, tan-bark, etc. The heat will drive off the inflammable gases, and, as little or no air can pass through the solid mass from below to mingle with them, they are lost. Even after the coal gas has been driven off, an insufficient supply of air will cause the formation of carbonic oxide. Thus it appears that the first indispensable requisite to complete combustion, viz., a supply of air proportionate to the wants of the fuel during the different stages of the process, *cannot be furnished by a furnace of ordinary construction.*

The Air Cannot Reach the Gas in a State of Purity. Let us now inquire how far an ordinary furnace will satisfy the second condition, viz., the supplying of *pure, uncontaminated* air to all portions of the fuel, whether solid or volatile. A very simple illustration on this point will suffice. Hold a small piece of paper over the chimney of a common kerosene lamp — it will not ignite.

Why not? Not for the want of heat; not for a deficiency in the supply of air, for there is a rapid current constantly passing through the chimney; but because the air has given up its oxygen to the hydrocarbons which come from the oil. This air will not support combustion, as it consists chiefly of nitrogen and carbonic acid. Would any one think of using this to support combustion in another lamp? But would it be any more unphilosophical to do this than to use the air which has been vitiated by passing over incandescent carbon for the combustion of a large amount of coal gas?

But this is just what is done in ordinary furnaces, and, instead of the volatile portion being burned, it is driven off unconsumed, oftentimes accompanied by a huge volume of dense smoke. If kindling wood be thrown on top of a fresh charge of coal in a common stove, it does not take fire, because the air which has passed through the mass of coal has lost its oxygen; even a small piece of paper can scarcely be lighted. How, then, can we expect that there will be a sufficient amount of air present to burn a large volume of gas?

Velocity of the Air Through the Furnace. A furnace which consumes only two hundred pounds of coal per hour requires for the gaseous portion of the fuel alone *ten thousand cubic feet of air*, and this is to be thoroughly mingled with *one thousand feet of coal gas.*

As the grate is constantly kept covered with coal, all this large volume of air must pass between the lumps of coal; consequently the velocity of the current must be greatly increased to supply the required volume.

It is estimated that the quantity of air passing through an ordinary fire chamber may be regarded as double that which is absolutely necessary for combustion; and the proportion of carbonic acid generated, therefore, is but half of that which it would be, were all the oxygen combined. The increase in weight in such burned air of the temperature of 212° being taken into account, it will require fifty-seven feet per second for the required velocity in a chimney one hundred feet high. This estimate is overrated, as there are many circumstances which have a tendency to diminish the velocity. But Dr. Ure found by experiment that the velocity in a chimney only forty-five feet high, and with a mean temperature as low as 270°, was between six and seven feet per second.

It requires a long time, at least several minutes, for a mere jar full of gases to become fully mingled, and that, too, when free from all disturbing influences. How can we resist the conclusion that it is impossible for the large volume of heterogeneous gases to mingle in the furnace, while moving in the same direction at the rapid rate we have seen?

How Coal Gas Escapes Combustion. The heated and rarefied coal gas rises, as it is generated, by its own levity, the air rushes up to fill the vacuum, and hence these masses cannot come in contact except in strata; for, by the law governing the motion of bodies, matter put in motion by one force cannot change its direction except by the application of some other force. Therefore it is evident that the rapid velocity of the currents in a furnace are antagonistic to the lateral or circular motion which is essential to diffusion.

The junction of the Mississippi and Missouri Rivers forms a striking illustration of the effect of currents in obstructing mixture. On account of the mineral matter which each has in solution, the water of each is sufficiently colored to distinguish one from the other, and these waters run side by side in the same channel for miles before they blend.

Mixture Incomplete in Ordinary Furnaces. The difficulties of duly mixing the air and coal gas were fully illustrated in the last chapter; and if we consider that the air in an ordinary furnace is admitted only at one aperture, and moves at a rapid rate in the same direction as the coal gas, we can readily perceive the impossibility of bringing about that intimate association of atoms which the inexorable laws of chemical association demand.

From the foregoing facts and illustrations we arrive at the following conclusions: —

1st. That during the combustion of bituminous coal and many other varieties of fuel large volumes of inflammable gases are generated.

2d. That when these combustible hydrocarbons are intimately blended with a proper volume of pure air, and the mixture heated to a temperature essential to ignition, their elements enter into chemical combination with oxygen, producing a large volume of flame and a high calorific effect.

3d. That the volume of inflammable gases is by far the largest just after a fresh charge of coal is added.

4th. That this additional quantity of coal obstructs the passage of air through the grate, so that there is an inadequate supply.

5th. That this deficiency causes the escape of pure hydrogen, an invisible combustible gas; of carburetted hydrogen, an invisible combustible gas; of carbonic oxide, an invisible combustible gas; of bi-carburetted hydrogen, an invisible combustible gas; or the hydrogen of these compounds of carbon and hydrogen may be consumed, and the

carbon changed from the invisible state of gaseous combination with hydrogen to a black, pulverulent form called smoke.

6th. That smoke may be produced by the admission of too much air at a low temperature, as well as too little at a low or high temperature.

7th. That in furnaces, as ordinarily constructed, the air can reach these inflammable gases only by passing through the highly incandescent and ignited carbon, by which a portion or all of its hydrogen is converted into carbonic acid.

8th. That this renders it incapable of effecting the combustion of the inflammable gases mentioned, whatever may be their temperature or however abundant may seem to be the supply of air.

9th. That even though a proper supply of pure air could pass through the grate to the inflammable gases, the time allowed by the current does not permit that thorough mixture required for chemical union between the oxygen and the inflammable gases before they have passed beyond the temperature essential for ignition.

10th. That this circumstance will occasion the loss of all the inflammable gases.

11th. That the coke, or solid portion, and those varieties of fuel containing little or no volatile matter require that every part of the burning mass shall come in contact with pure air.

12th. That in ordinary furnaces this is impossible, as the upper portion can receive only contaminated air — air which has given up a portion of its oxygen to be converted into carbonic acid.

13th. That if there be a deficiency in the supply of air in any portion of the burning mass, carbonic *oxide*, instead of carbonic *acid*, will be the result, and even the carbonic acid which is produced in those parts of the fire chamber which have a due supply of air will, in passing over the heated fuel, be converted into double the volume of carbonic oxide, and escape unconsumed.

14th. That whenever the escape of any combustible gas from the furnace occurs, two losses at least are sustained. First, the furnace is robbed of a large amount of heat required to raise this portion of the fuel from a solid to an aeriform state. Second, all the calorific effect will be lost which would have been produced had these inflammable gases entered into chemical union with oxygen.

15th. That the loss sustained in the form of smoke is very small in comparison to that in the form of invisible gases, carburetted hydrogen, bi-carburetted hydrogen, and carbonic oxide.

16th. That when pure hydrogen is allowed to escape at a high temperature it sometimes combines with nitrogen, producing a gas called *ammonia, which is more destructive to fire than water itself.*

How These Losses May Be Prevented. Numerous inventions have come before the public for effecting "the *combustion of smoke* and securing economy in the use of fuel."

Our space does not permit of an extended examination of all their respective claims. So far as our acquaintance with them extends, most of them are founded on the erroneous idea that, if they can pass the smoke (combustible gases, they mean) over intensely heated bodies, it will be consumed.

While it is a leading condition of the combustion of any gaseous body that it be mingled with a proper supply of oxygen at a given temperature, nevertheless these inventors have gone on the supposition that heat alone will effect their combustion; but, as has been shown, no degree of heat can consume carbon, carburetted hydrogen, or any other solid or gas. Indeed, heat has nothing to do with their combustion only so far as to induce chemical action between combustibles and the supporter of combustion, when brought in contact.

Heat may effect a *decomposition* of fuel, but *decomposition* is not *combustion.* Heat may cause visible smoke and invisible carbonic acid to combine and produce invisible carbonic oxide, and thus the smoke appears to be consumed.

But this is not combustion; it is a *heat absorbing* rather than a heat producing process. Because hot bars of iron or "red-hot" fuel or "glowing coals" will burn a boy's fingers or a cat's nose, it is not a logical conclusion that it will burn carbon or carburetted hydrogen.

Any method that will bring any of the combustible products of imperfect combustion into chemical union with oxygen will prove efficient in correcting this evil.

But why create an evil and then devise a remedy? Why not first find the condition necessary for perfect combustion, and construct a furnace which shall meet these conditions, instead of half burning the fuel, and then undertaking the difficult task of *burning the combustible products of an imperfect combustion?*

When the flame of a lamp is dull and red, and sends off a volume of black smoke, do we set ourselves to work to burn that smoke? Who ever heard of a lamp burning its own smoke? When petroleum first came into use, it could not be burned in an ordinary lamp; it sent off a dense volume of smoke, and created an intolerable odor. The cause was ascertained, and the construction of the lamp so modified as to render its combustion so complete that it is now regarded one of the finest illuminators in the world.

RECAPITULATION.

The aim throughout this review has been to point out to the practical man the principles on which alone the complete combustion of fuel can occur, and we again assert that the greatest economy in its use can be secured only when the *scientific conditions of the process are clearly understood, and made the foundations of practice.* These conditions have been defined and illustrated by the diagrams.

There can be no doubt as to the fact that the average temperature of a mixture of air and coal gas in the furnace is higher when it is fed with air at 500° than at 60°; and, since a high temperature is indispensable to combustion, we naturally arrive at the conclusion that heated air would be more efficient in the process.

We have now only room for the following conclusions:—

1st. It has been shown that it is impossible to pass a sufficient quantity of air through the incandescent carbon of the grate for the complete combustion of the volatile portions of the fuel.

2d. That the admission of a large body of cold air over the surface produces too powerful a refrigerating influence to insure the complete combustion of the inflammable gases.

3d. That in heating the air previous to its introduction into the furnace, it necessarily becomes rarified.

4th. That while a given volume of rarified air contains a smaller number of atoms of oxygen than the same volume of condensed air, yet it has been shown by experiment that, within certain limits, the more rarified the air, the more complete the combustion.

5th. That this more complete combustion in rarified air is chiefly due to the greater mobility of rarified gaseous bodies, which must produce a *more rapid admixture* of the air with the combustible gases than would otherwise take place.

6th. That while this increased rapidity of mixture causes a diminution of light, yet it has been shown by experiment that the calorific power of rarified flame is not diminished but increased.

7th. That by the introduction of heated air in small jets over the surface of the fuel, a sufficient supply of oxygen may be admitted, a much larger contact surface given, a powerful refrigerating influence avoided, a more rapid mixture arising from the increased mobility of the particles obtained, and consequently the whole process of combustion quickened in intensity and rapidity, and rendered more complete.

FIGURE No. 25.

THE JARVIS PATENT HOT-AIR FURNACE, FOR SETTING STEAM BOILERS.

Economy on all fuels, with power to burn the cheap grades, slack and other fine fuels.

JARVIS ENGINEERING CO., 61 OLIVER ST., ... BOSTON, MASS.

The Jarvis Furnace and Boiler Setting. The characteristics of this setting show a careful study of not only the scientific problems involved in the burning of fuels, but also the more difficult work of treating the fine and slack coal, in general a waste product, and securing a high duty therefrom. The general idea of their arrangement appears to be much the same as those suggested and employed by English engineers.

The Jarvis furnace and setting, as applied to steam boilers, is without doubt the survival of the fittest of the many plans which have from time to time been added to the patent list, and, unless we can see and reach further, and escape all hand firing,—personal tinkering with the supply of coal to the grate,—this is doubtless the best and simplest remedy that can be applied to the average shell or tubular boiler of to-day.

Briefly, the plan is a peculiar way of laying the side and bridge walls to form flues through which the air for supplying the fire *above* the grates is drawn, the principle being that what the fire needs, in addition to air through the grates, is pure hot air discharged on top the burning fuel, to mix with the gases generated above the grate.

The air heated in its transit through the passages is discharged in jets through fire brick plates on the side of the furnace and at the bridge wall, and, when it comes in contact with the gases, immediately bursts forth into flame with intense heat, resulting not only in large economy of fuel, but also increased capacity.

It will be noticed that these air chambers are in the side of the fire chamber, and the interior wall is perforated fire-brick through which the air passes. This meets the second condition for perfect combustion, viz: That every part of the burning mass, whether solid or gaseous, must be brought in contact with *pure air—air uncontaminated with the products of combustion.* By this arrangement the combustible gases and ignited carbon are inside, and pure air surrounding these on the outside, while the hundreds of orifices serve to bring these elements in contact with each other, and at the high temperatures necessary for chemical union and perfect combustion.

One of the most important advantages gained by the use of this furnace is the large increase in the capacity of the boilers to make more steam and do it quickly.

This is substantially the condition described and illustrated by the apparatus of Sidney Smith, to which the following description was originally applied by Dimond, including the chapter on the proper construction of furnaces—passed forward to make room for the pulverized, liquid, and gaseous fuels.

The essential condition for perfect combustion is here met; namely, that the supply of air is regulated by the demand. No more air will enter through any one orifice than can be absorbed by the gas with which it comes in contact. This is a very important point, because an excess of air, beyond what is absolutely required for chemical union, must have an injurious refrigerating influence; but when all the oxygen of the air which passes through the perforations enters into chemical union, heat is constantly developed, so as to overcome the cooling effect of the air.

By passing the air in by jets, minute currents are created at those points where it is the hottest,—these of course are where combustion has already commenced. The heat also causes the combustible gases to rush towards the jets of flame, to take the place of the rarefied products of combustion which are constantly driven away by the current.

When a fresh charge of fuel, containing any considerable portion of volatile matter, is added, a sufficient supply of inflammable gases is produced to cause the whole interior of the fire chamber to become filled with streams of flame, while sufficient air is admitted to the solid portion to keep it in a state of intense incandescence.

The interior of the fire chamber becomes highly heated, and in a short time the heat is communicated, both by conduction and by radiation, to the air chambers. The cold air, in passing into these chambers, comes in contact with a large surface of heated material, and consequently becomes evenly and moderately heated. It now passes with considerable force through the perforated walls, and impinges against and mixes with the gases thrown off from the heated fuel on the grate.

I have given these improved settings for hand firing and mechanical stoking prominence and illustration as the best remedy for the crude and impractical boiler setting commonly employed, and for the signal economy that may be reached while using the fine and slack coals of the hard and soft variety, at about half the cost of lump coal.

I may, however, here remark, that the best results would be attained in the Jarvis, and in similar settings using slack and fine fuels, by the employment of a forced draft in the ash pit in preference to creating the necessary draft by the use of a high or a hot chimney.

For many other applications of air, hot and cold, to the furnaces of steam boilers, see "Fuel: Its Combustion and Economy," D. Van Nostrand, N. Y., 1879.

Laying aside possible imperfections of construction or a failure to obtain intelligent management and care, it should be clear to the practical reader that this construction of furnace will meet the prescribed and desirable conditions in the following order:—

1st. By giving complete control, in respect to quantity, over the admission of the air to the solid or carbonaceous portion of the fuel, which serves to regulate the volume of the gas set free in any given time.

2d. A similar command over the admission of the air to the gaseous portion.

3d. The air is introduced to the entire gaseous, as well as the upper, part of the carbonaceous portion of the fuel from a chamber wholly unconnected with the ash pit. No deterioration, therefore, of the air can take place by a loss of a portion of its oxygen or by its becoming mingled with the products of combustion, thus completely overcoming a very serious impediment to complete combustion that exists in the ordinary furnace.

4th. The air is introduced at *right angles* to the current of combustible gases, which overcomes the obstruction to their incorporation with air, arising from their rapid upward motion.

5th. By introducing the air in *jets*, it acquires a momentum which enables it to penetrate the mass of combustible gases in the fire chamber, thus materially assisting the process of diffusion.

6th. The air, passing in *jets* at right angles to the ascending currents of combustible gases, also serves to overcome the impediment to the complete mingling of the air and gases which arises from the varying specific gravities of the different aeriform bodies found in the furnace.

7th. By restricting the admission of air to small streams, no great excess of air can reach any portion of the gas beyond what is required for perfect combustion, thus preventing any serious cooling effect from the introduction of air into the furnace.

8th. By admitting the air in streams, the *largest possible surface* is presented for the diffusion and mutual contact between the atoms of the combustible gases, thus completing the required mechanical mixture before either has passed the region where the temperature is too low for chemical action.

9th. By passing streams of air over the entire surface of the flame bed, an excess of heat is prevented in any one locality, and a longer extent of available flame is also given to the boiler.

10th. The heat, which in furnaces of ordinary construction is lost at the sides, both by conduction and by radiation, is in this arrangement used in heating the air previous to its introduction into the furnace.

It should be clear to those at all used to the working of fires that a furnace which will suit admirably for one kind of coal will not answer for another; each fuel must be separately considered.

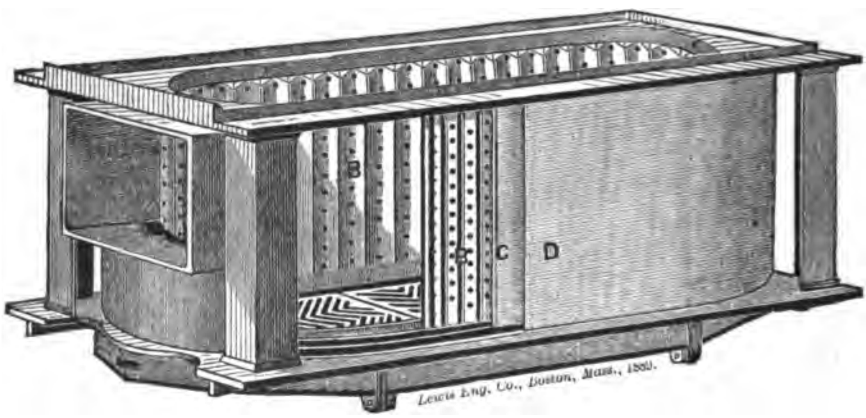
Sidney Smith in 1876–77 did some important experimental work in the way of effecting more complete combustion in furnaces, *and was really the promoter and moving power behind Professor Dimond, who wrote the treatise, "Chemistry of Combustion,"* referred to in our Introduction and in the letter of Mr. Smith to the author.

The principles of combustion which Ami Argand applied to the lamp Mr. Smith applied to the furnace, and constructed a fire chamber presenting a large surface for contact between the atoms of combustibles and of the air. By the use of fine coal in his experimental apparatus heat was obtained of sufficient intensity to melt iron.

It is proper here to remark that the invention was exhibited at the Worcester County Mechanics' Association September, 1886. The following from the report of the judges may interest those who desire to know how far this attempt to harmonize theory and practice was successful:—

"From the experiments made in our presence with stoves and boiler furnaces, the committee cannot resist the conclusion that the principles of perfect combustion theoretically and practically have been satisfactorily demonstrated. The committee awards a *silver medal.*"

Sidney Smith's Method of Effecting the Complete Combustion of Fuel by the Admission of Air to the Fire Chamber in Small Jets.



The fire chamber is represented with the trap closed. A portion of each of the three perforated walls is removed, showing the interior of the fire chamber, the grates, and the spaces between the walls. B is the interior wall. C is a wall of thin metal, more finely perforated than B, and surrounding it at a distance of about three eighths of an inch. This is kept in place by a flange on the base and cap of the fire chamber. D is a second wall of thin metal with perforations still finer than those of C. This is separated from C three eighths of an inch, and kept in place by a second flange on the base and cap. *This gives three perforated walls with air chambers between, entirely surrounding the fuel, and through which air is admitted for combustion.*

Note.—Mr. Smith continues his work at 61 Oliver street, Boston, Mass., on the steam boiler furnace, latterly by auxiliary coils, which, while largely increasing evaporation, duly arrests the deposits and sediments, so injurious to all classes of boilers.

CHAPTER IX

PULVERIZED COAL AND OTHER FINE FUELS.

BEFORE leaving the solid fuels and the fine or slack coals, a further review of the soft or bituminous variety seems desirable, and its connection with furnaces especially designed to utilize this coal, and at the same time abolish the smoke nuisance,—for which there is now no longer an excuse.

There are several conditions of coal not in the lump or solid state, and other substances available for fuel to-day, not considered by Dimond, but to which his principles of combustion equally apply. These and the liquid and gaseous fuels, being of the first importance and interest to all engineers and students, will be considered.

In England this matter has been the subject of frequent parliamentary investigation and discussion. There, about thirty millions (30,000,000) of tons of coal are mined annually and raised to the surface to be thrown away, or to be burned in heaps to be gotten rid of. In this country this waste amounts now to about *fifteen million tons annually.* Every one who has visited our coal mines has seen with surprise the vast accumulations of waste coal, broken too fine for use by the present methods, which encumber all the mining districts.

THE USE OF PULVERIZED COAL IN GENERATING STEAM.

As every fuel has the power of generating by combustion a fixed quantity of heat, a quantity which it is impossible at present to convert into its maximum useful effect by any method, the problem therefore becomes a question as to what is the method that will enable us to approach most nearly to this maximum useful effect. Part of the potential heat is never developed, because not all of the carbon and hydrogen can be oxidized, or, rather, peroxidized. Part of the heat developed by combustion is carried out at the chimney, and lost altogether, thus failing to exert any useful effect by absorption into the boiler. Part of the heat absorbed into the boiler is lost by radiation from the external shell before it can be converted into work in the steam cylinder, and so on, each source of loss being very serious, and robbing the engineer of a large percentage of his resources.

English engineers and experimenters early gave this matter their attention, and many plans and experiments were tried to secure smokeless chimneys and a greater economy in the use of soft and bituminous coal.

The question of improvement in the setting of boilers and the construction of furnaces was early advocated by Charles W. Williams and several contemporaries in England, 1850 to 1860 and almost every variety of change of furnace, construction and application of air, was tried, with more or less success.

As showing the general understanding of intelligent engineers, even thirty years ago, C. W. Williams wrote:—

"I perceived the absence of any well-founded principle in the construction of the boiler—that the part on which most depended appeared least understood and least attended to, namely, the furnace.

"I saw that although the great operations of combustion carried on in the furnace, with all that belongs to the introduction and employment of atmospheric air, were among the most difficult processes within the range of chemistry, the absence of sound scientific principles still continued to prevail; yet on these must depend the extent or perfection of the combustion in our furnaces.

"While every other department was making progress, all that belongs to the combustion of fuel, the prevention of smoke, and the wear and tear of the furnace remained in the same *status quo* of uncertainty and insufficiency; and even that boilers and their furnaces constructed within the last few years exhibit still greater violations of chemical truths, and a greater departure from the principles on which nature proceeds. As much uncertainty as to success of a new boiler has prevailed as when I first began operation thirty years ago, and few boilers exhibit more in the way of effecting perfect combustion or economy of fuel than those of any former period since the days of Watt."

As further exemplifying the uniformity of all writers as to the requirements of furnace construction, and the elements to be chemically treated, we may cite *Williams*, *Longridge*, *Richardson*, *Daniels*, *Wilson*, and *Clark*, of the English engineers, while *Dimond*, *Haswell*, *Barr*, *Tower*, and *Thurston* have written for American readers, all taking the same ground, and asserting that the conditions within the furnace are those *defined by chemistry and chemical combinations*. The same view is held of the liquid and gaseous fuels, and all success in the application of oil and gas have been, and will continue to be found, where the *chemical combinations of each fuel have been first considered and practically provided for.*

As we have seen, the conditions under which coke and anthracite coal enter into combination with oxygen are much less complex than in burning bituminous coal. The point to be observed is, that a large quantity can be kept on the bars, there being not so much danger of the carbon passing away without its supply of oxygen. In bituminous coals the bituminous portion is only serviceable for heat when converted into gas, while the carbonaceous portions are consumed only in a solid state; and they must be separated, as explained, before they can be consumed.

Thus, when coke or anthracite coal is burned, the products are carbonic acid gas and nitrogen; while, with bituminous coal, we have carburetted hydrogen and nitrogen and carbonic acid gas or oxide.

Much attention has been given to this subject and many experiments made to test the conditions under which the fine bituminous coals could be advantageously burned.

The most of these, and certainly the successful efforts, have been in the line of mechanically fed and tended furnaces, or mechanical stokers, as they were called in England, where the idea originated.

There are many objections to hand-firing when taken in connection with steam-boiler furnaces. In order to get the best results from such a furnace, the firing should be as nearly constant as possible, in order that chemical action may go on undisturbed.

Hand-firing must, from its nature, be intermittent, and therefore irregular. When the fire is brisk and a boiler steaming rapidly, the opening of the furnace doors, in order to admit a fresh charge of fuel, and thus allowing a draft of cold air, often below the freezing point of water, to impinge against the heated plates of the boiler, at the same time lowering the temperature of the gases in the furnace, and, added to this, the deadening of a brisk fire by a fresh charge of coal, always in excess of actual requirements and too often unevenly spread, is certainly not conducive to the highest economy.

The advantages of continuous firing were pointed out early in the present century, and a great number of devices have been tried from time to time, many of which have long since disappeared to give place to better contrivances to this end.

There have been several attempts to secure the introduction of fuel into the furnace by mechanical means, ending in the idea of reducin[g] the coal to powder in order to get a regular supply and at the sa[me] time an *intimate mixture and contact between the fine carbon and oxygcn of the air, on which the coal was floated or blown into the furn[ace]*

*It appears that Mr. John Bourne was the first publicly to advocate, in his patent of 1857, the use of coal or other fuels in the form of dust, for the generation of heat in furnaces. Aware that the more intimately and equally the mixture of fuel and air for combustion can be effected and regulated, and that necessarily the smaller the constituent particles of the fuel can be rendered, the more effectively and promptly can the desired mixture be accomplished, he says, in the edition of his "Treatise on the Steam Engine" published in 1861, page 358: "It appears to us that the fuel and the air must be fed in simultaneously, and the most feasible way of accomplishing this object seems to be in reducing the coal to dust, and blowing it into a chamber lined with fire brick, so that the coal dust may be ignited as soon as it enters."

Mr. T. R. Crampton, as early as the year 1868, instituted a long course of experimental investigations into the best means of generating and applying heat from the combustion of powdered coal.

"It is not only necessary," says Mr. Crampton, "to have the means of bringing together at will the proper equivalents of air and coal to insure perfect combustion, but it is essential that the size of the coal should be determined, and that it should, during its flotation through the furnace, be so conducted that any overcharged and undercharged currents of air and coal shall be continually reintermixed until the whole of the carbon is consumed."

In delivering a mixed current of air and coal dust through a pipe, it was discovered by Mr. Crampton that at times, although an absolute mixture entered the pipes, conveying the coal and air to the furnace, yet, under certain circumstances the materials became separated, — more particularly when they had to pass through bends, — the coal being carried by its superior momentum to the outer part of the interior of the bend, and being thus led to issue from the pipe into the furnace, as a close stream unmixed with air. To compensate for this tendency to separate, Mr. Crampton, in his experiments with fixed combustion chambers, introduced the currents by several inlets inclined downwards, so as to strike the floor of the chamber, and to impinge upon each other. The air and the fuel, playing over the floor, became readmixed, and were at once carried over the bridge into the heating chamber.

The coal was reduced to powder sufficiently fine to pass through a 30-sieve, at a cost for labor of 6d. per ton; or, including all charges, 1s. per ton. The air current was produced by a fan blast.

In the application of the new system to puddling furnaces at the royal gun factories, Woolwich, Mr. Crampton constructed the furnace in two compartments, — a combustion chamber, A, and a puddling chamber, B, — opening into each other. It is not the purpose of the author to enter into the details of construction.

*D. K. Clark's "Fuel; Its Combustion and Economy."

***Stevenson's Apparatus,** the invention of Mr. G. K. Stevenson, of Valparaiso, was at work when seen in England under a Cornish boiler, from which the grate bars had been removed, and in the furnace was placed a species of fire-clay retort, the sides of which were perforated with numerous holes about a half inch in diameter. The air and powdered fuel were driven in together through a pipe six inches in diameter, a few fire brick being arranged in the flue behind the retort, to act as a bridge wall.

The coal is reduced to a fine powder by a small disintegrater, which delivers into a closed sheet-iron tank, to prevent the escape of dust. It is brought to the condition of a somewhat coarse powder, and is not impalpable.

In the base of the hopper is a small delivery wheel, in the rim of which are notches. These notches are provided with slides worked by a very simple arrangement, which compels them to obey the action of gravity and fall to the bottom of the notches when they are at the top of the wheel.

The notches then fill with coal dust, and, as the wheels revolve, the slides being thrust downwards, push the coal out of the notches into the air tunnel. The rate of delivery of the coal can thus be accurately fixed by regulating the speed of the wheel, which is driven by friction in a way which will be readily understood. In order to mix the coal dust with the air, a twisted plate of metal is put in the air tunnel. This causes a rotary motion in the current and produces the desired effect.

The air is supplied by blower driven by belt from a lay, or counter-shaft. The apparatus was started by lighting a fire in the retort; after that has burned up, the blower is set in motion, and coal dust and air fed into the retort.

Several experiments have been carried out to test the value of the apparatus. One by Mr. T. B. Jordan lasted a little less than six hours. The boiler evaporated 5,984 pounds of water from 81° with 720 pounds of coal, or 8.312 pounds per pound of coal, gross.

THE INVENTION AND FURNACE OF MR. HOLROYD SMITH.

This furnace may be cited as combining many of the requirements noted as desirable; his plan was not, however, a *surface feeder*. "He introduced the fuel from *below the grate*, through hollow grates or screw cases, each containing a screw, or worm, the turning of which elevated the fuel from the cases directly upon the grate bars, so that the volatile gases were extracted by the incandescent fuel above it, and were burned, as fast as evolved."

*"Combustion of Fuel." Wm. Barr, 1879.

THE WHELPLY AND STORER PROCESS AND MECHANICAL FURNACE.

Although this process is not at present prominently before the public, owing doubtless to the great changes in the fuel supply produced by the discovery and application of oil and natural gas, we deem it of sufficient interest to review briefly this method; as, should the supply of gas diminish, as able geologists and engineers predict, then a process which will convert the millions of tons of anthracite coal waste into a valuable heating gas will be remembered and eagerly sought for. Their method consists in pulverizing the coal to an extreme degree of fineness, and blowing it into a combustion chamber, where it is ignited and burns in the air which floats it.

ACTION OF PULVERIZER.

Conceive an ordinary blowing fan with the following modifications: The box is about eighteen inches in diameter, and about the same length. Instead of opening at both ends, one end is tight around the journal. The box is divided into two chambers by a diaphragm, so that really we have two fans on the same shaft, and their boxes communicate by a hole in a diaphragm around the shaft. The fan at the closed end of the box is in the form and function of a blowing fan. The outer fan is the pulverizer.

The coal is fed into the open end of the pulverizing chamber, is caught by the swiftly revolving paddles and reduced to powder, and is then sucked by the fan through the diaphragm, whence it is expelled by the ordinary tangential pipe along the blast. The coal is fed in the form of coarse gravel; it is delivered as fine as flour.

By this process the fine coal now thrown aside as waste is all useful and valuable, for the finer the fuel the better the result. Hard coal does better than soft coal; and we think that this opens the way to some wonderful changes in the use of fuel. The time will come when the crude methods of to-day will be viewed with surprise and awe at the waste they entail.

It is not proposed to obtain any more *heat* out of the combustion of a quantity of coal, but merely an increased *temperature* from the same quantity, by diminishing the volume of gas through which that heat is distributed.

The economy of high temperatures over low ones (provided they are obtained without large increase in the consumption of fuel, and provided also they are not so great as to act destructively on the materials subjected to them) is vastly greater than would at first seem, and out of all proportion to the increase.

The best results are obtained with bituminous coal. In common grate burning, anthracite usually gives a more intense heat than soft coal, though its thermal equivalent is theoretically less. But in burning soft coal, the distillation of hydrocarbon vapors from the upper layers of the fire absorbs considerable heat; and, as these are subsequently burned only very imperfectly and with great loss by smoke, much of the thermal power of this coal is lost. In the reverberatory furnace the long flame of the bituminous coal is required to fill the hearth, while anthracite would yield only an intense heat in the fire-place, and a flame short and of small intensity in the hearth. With *pulverized fuel*, the full, long, abundant flame, and the great temperature due to the higher thermal equivalent of bituminous coal, are both realized — a fact abundantly sustained by practice, and in itself a proof that the combustion is more complete.

But very good results are obtainable with anthracite, the chief objection to it being that it requires more power to pulverize it, and that it does not ignite so readily.

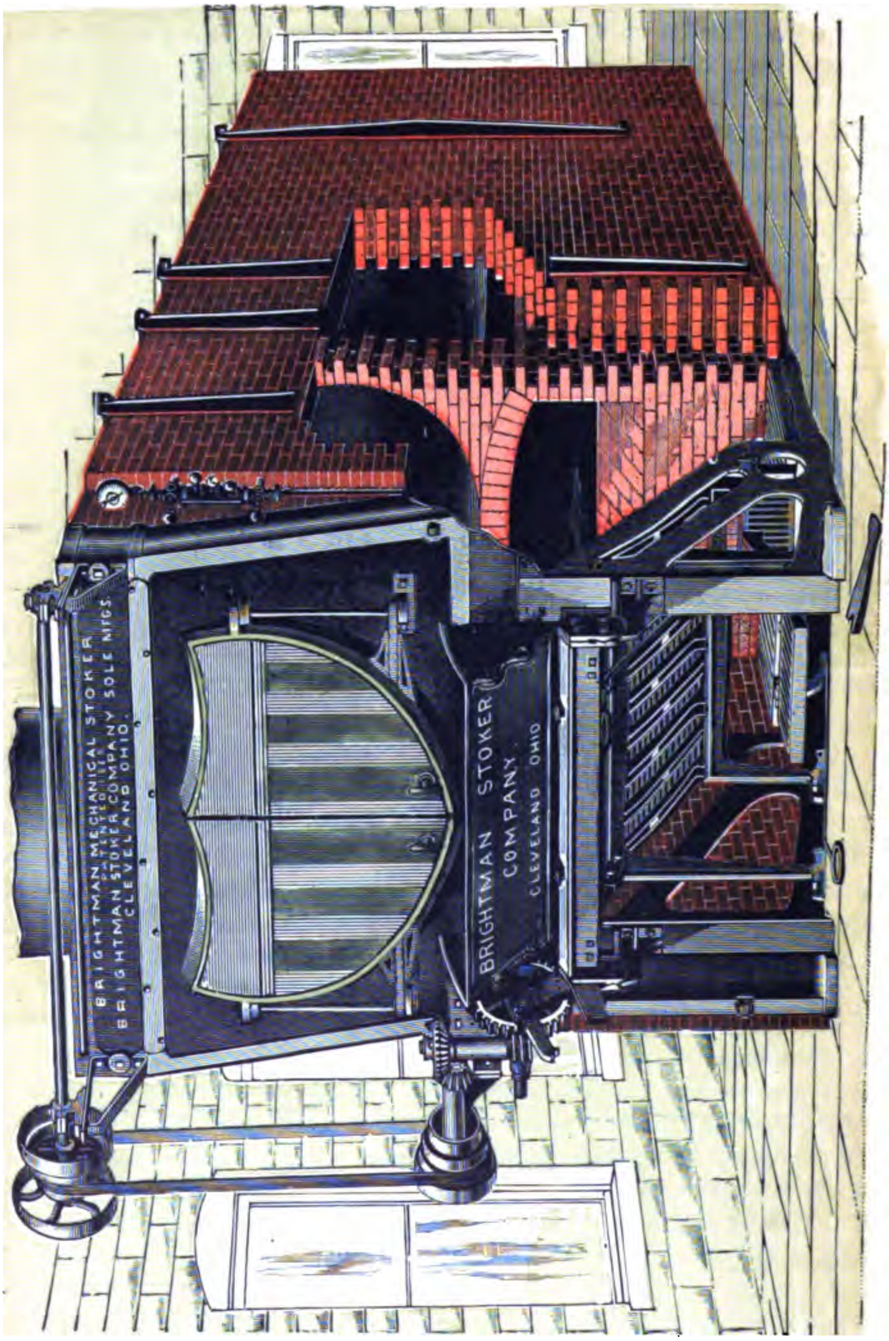
So long as the fuel in a *solid form* is burnt on a grate, as at present, the constantly varying demand for the proper quantity of air can seldom or never be complied with; and even though the quantity should be supplied correctly, as far as ordinary appliances, manipulated with ordinary intelligence, admit, still the difficulty is only partly overcome, because after the air has entered the furnace the system of combustion does not effect a proper mixing of the gases and air, and, *unless there be an intimate mixture, perfect combustion is impossible.*

Scientists and practical men of affairs have alike investigated this process, and it has received from them the highest encomiums. Going back to the early stage of coal, it is admitted that atoms of carbon form its basis, and, being solidified, form coal, as we know it. The process under consideration reduces coal to flour and feeds it to the furnace, and the result is intense heat with no waste; no unconsumed carbon goes out of the smoke-stack in the shape of smoke or soot or gas.

From a circular of the Atomized Coal and Furnace Company of New York, we take the following figures of results. By the report of Moses G. Farmer, the several trials made by him gave an average economy in cost and amount of fuel, as compared with the *usual* methods of firing under boilers of the same dimensions, of *thirty-eight and one-third per cent*, this economy being made up of two items, — the gain in effective value of the fuel as an agent of combustion, and the less cost of the anthracite and bituminous slack used. Experiments by U. S. engineers did not sustain the above high result. There may also be consulted reports on this process by Charles E. Emery, L. R. Greene, C. E., and J. G. Benton, Lieutenant Colonel, commanding at the Springfield Armory.

Plate No. 26.

*** The Brightman Mechanical Stoker as applied to the Regular Return Tubular Boiler.**



* For other applications, see Plate, Reports of Efficiency; also, Table of Evaporation No. 32.

MECHANICAL FIRING AND STOKERS IN THE UNITED STATES.

While progress and inventions for securing the economy of fuels have gone on in England and elsewhere, we have not been idle, and have something of merit to show, as the result of inventive genius and business sagacity.

The intelligent reader of the foregoing pages, while at no loss to understand the grave defects in the ordinary furnace construction, will also desire further knowledge of the improvements which have, in so large a measure, checked the waste, while rendering available fuels of lower first cost, but of equal efficiency in the production of steam.

Certainly, nothing will surprise the student and practical reader more than that a class of work of such importance as furnace construction should so long have been left and relegated to the hands of men so poorly fitted by education and occupation to either understand the requirements of furnace construction or provide for them.

Perhaps two thirds of all the horizontal tubular boilers set in this country get no further attention than some red and blue lines furnished by the architect, and the laying up of walls by the mason; a third party, the foundry-man, coming in to supply fronts, grates, and fittings, the like of which were in use at the time Watt set his first boiler; the weight of these castings being where the foundry interest comes in and the owner's leaves off. True, some improvement has been effected in the main factor, the grate bars, and many patents encumber the list; the *movement* of the bars may be considered the really valuable feature secured, which enables the fireman to cleanse his fires without opening the doors and chilling the gases, while roasting himself.

While the shell of all kinds of wrought boilers has been greatly improved by the introduction of machinery for cutting, punching, and riveting plates, and the strength of these largely increased by the substitution of steel, also by the invention of improved grates, but little advance has been made in the *setting of the boiler* and the *construction of the furnace;* and it is safe to say that, of all operations connected with mechanical engineering, none of these shows up to such poor advantage as the steam-boiler furnace and the brickwork that surrounds them; while the whole process of feeding and burning the lump coal under the average heating and power boiler *is the crudest and most wasteful process that exists to-day; at once a reproach to our boasted intelligence* and experience of fifty years in the use of boilers and fuels generally.

The Brightman Mechanical Stoker of Cleveland, O., and the Murphy Furnace of Detroit, Mich., may be cited as the embodiment of what is really valuable in the later constructions of mechanically fed furnaces.

These two mechanical furnaces are a radical departure from all other attempts, in this country at least, to abate the smoke nuisance, while using the soft and bituminous coals—preferably the fine slack or waste coal.

The Brightman furnace is distinguished by the entire absence of the feeding doors used in ordinary furnaces; the fuel is supplied in such a manner that the feed opening into the combustion chamber is kept constantly filled by the entering fuel, preventing the entrance of cold air through the feed hopper, and avoiding the periodical *cooling*, *condensation*, and *waste* of combustible gases, above referred to.

The furnace front is made of cast iron in the usual form, with the exception of the ordinary feeding and ash-pit doors, which are entirely abandoned; that part of the ordinary furnace front below the lower boiler line being entirely removed.

The grate bars are inclined at an angle of 34° from the horizontal, and are made with lateral projecting lugs, which overlap each other as shown in the illustration. By this construction all *vertical* openings through the grate are avoided, thus preventing the great waste which occurs ordinarily by the falling of fine fuel through the common grates into the ash heap below.

The fuel entering the grate opening is delivered at the top of the grate bars; whence the reciprocating motion of the grate bars, combined with gravity, causes it to move regularly along the grate bars towards the rear of the furnace.

All fuel on the grate bars moves simultaneously. This movement is positive and uniform, though it may be varied in volume and rapidity as the demand for steam production changes. This constant and regular movement insures a uniform thickness of incandescent fuel and an ample supply of air through the grate bars. The motion of the grate bars is longitudinal only, and in a horizontal direction, and is confined to each alternate grate bar. This motion may be varied from one fourth of an inch to one inch, as may be required; the adjustment of such variation being easily and quickly made at any time without stopping the machine.

The constant movement of the grate bars prevents the formation thereon of clinkers; ashes and other incombustible matter, with some unburned fuel, pass from the inclined grate to a rear grate situated six inches below the rear end of the principal grate.

The ashes fall through this rear grate to the ash pit below. The clinkers remain on the rear grate, their heat being absorbed and utilized in heating the air which enters through this part of the furnace, and by supplying heated oxygen promotes combustion.

In the Brightman furnace little or *no smoke is produced.* By the automatic feeding devices the coal is regularly supplied to the grate, the gases are generated moderately and *uniformly*, and the fire is kept at an *even* and *sufficient* temperature to consume the combustible gases. The admission of air required to support combustion is *uniform* and adequate thereto.

There have been numerous so-called smoke burners in the market, some of which have been proven more or less efficient in the avoidance of smoke; but the experience of all users of such devices demonstrates that they are far from economical and of short life, and are usually open to other very serious objections.

The *burning of smoke* is entirely impracticable. Smoke may be burned, however; so may water, fire, clay, asbestos,—it is only a question of the intensity of the heat required. Such intensity of heat as is necessary to burn smoke cannot be economically applied in a boiler furnace. It requires an unnecessary expenditure of fuel, is ruinous to the boiler and other surroundings, and soon destroys the smoke-burning device itself.

Smoke is unavoidable in ordinary furnaces, and, so long as they are used, just so long shall we have the smoke nuisance with us. Careful and intelligent firing with clean lump and nut coals and an excess of boiler capacity may somewhat lessen this evil; but such care and intelligence are not usual, lump and nut coals are expensive in comparison with "slack," and excessive boiler capacity is far from common. The smoke nuisance can only be avoided in a practical way by the adoption of furnaces devised for this purpose. The Brightman furnace will, when properly used, do away with 95 per cent of the smoke, and will produce more steam, burning "slack," than any flat-grate furnace in use can with lump or nut coal of like quality.

The writer's personal examination and use of this furnace began in 1885, after his reconstruction of the heating and ventilating apparatus at the Insane Asylum at Buffalo, N. Y. It was under instructions from the Commissioners that he made an extended examination in the various fuels and furnaces, both in and out of the state. This resulted in a report and recommendation of the Brightman furnace, coupled with the statement that at least one third of the total fuel bill might be saved yearly to the institution.

The coal required up to that time was some eighteen hundred tons, anthracite egg, and cost never less than $4 a ton, or a total expenditure of over $7,000 per year; *after the reconstruction* $3,992, *or net gain with interest*, $3,180—46 *per cent saved per year.*

REPORT OF THE MANAGERS OF THE BUFFALO STATE ASYLUM FOR THE INSANE, FOR THE YEAR 1885.

"The extensive repairs and improvements of the heating apparatus, which were noticed in our last report, have been continued and are now approaching completion. The most important change has been the substitution of bituminous nut and slack coal as a fuel in the place of anthracite coal. This involved the introduction of special apparatus for feeding the boilers and of a new style of grate bars.

"After a full examination of the different methods employed, the committee to whom the matter was referred, acting under the advice of Mr. John H. Mills, an expert in steam heating, adopted the furnace made by the Brightman Automatic Stoker Company of Cleveland, O., as promising the best results at the least outlay.

"This was placed in position during the fall months, and has since been in use. We are able to give the result of a trial with the new furnace using nut and slack, during the first three weeks in December. *The average gain per day for the twenty-one days is* $12.96, *or for the month about* $400.

"From these facts it seems safe to estimate for the five months of the heating season $2,000 saved, or the entire expense of the apparatus, cutting boilers, and change of smoke flues."

FROM THE REPORT OF THE COMMISSIONER, 1886.

"The Board, in their report of last year, described at considerable length the changes and improvements which had been made in the heating apparatus of the asylum, and gave the result of a limited experience of a few weeks in the form of a report made by the engineers.

"This was extremely favorable, both as regards quantity and uniformity of heat obtained and the economy of production. They can now report that their expectations based upon this short trial have been more than realized in the results of the full year. In changing from the use of anthracite to bituminous nut and slack, and in introducing the automatic stoker, they were promised a probable reduction of one third in the cost of the fuel. *This, however, has been exceeded, as the actual saving was nearly one half.* Since the opening of the institution, including the time when only two wards were in use and the gradual filling up of the asylum until the whole eleven wards were occupied, *the average cost of fuel for the five years was* $7,000 *per annum.* During the past year the total cost for *fuel was* $3,992.20.

"As showing the work done by the heating apparatus, we present a table from the records of the month of February, 1886. This shows the daily average outside and inside temperature, the total amount of radiating surface, the amount in use each day, and the amount of coal required to effect the heating." (See table No. 7 instead of the abridged one referred to.)

TABLE No. 7.

CONDITIONS OF WARMING AND VENTILATING SIX BUILDINGS, INSANE ASYLUM, BUFFALO, N. Y., 1887.

Ventilation Effected by Mills Fans, Actuated by Steam Engines Exhausting into Heat Chambers.

AIR CHANGED TWICE EACH HOUR. 2,188,767 Cubic Feet. NO. OF INMATES, 400.

Administration B.,	561,980	Vent Flues,	43 = 43 sq. ft.	Ward C, . . .	301,638	Vent Flues,	68 = 30 sq. ft.
Ward A, . . .	456,106	" "	112 = 49 "	Ward D, . . .	297,059	" "	72 = 31 "
Ward B, . . .	449,119	" "	100 = 40 "	Ward E, . . .	122,865	" "	32 = 14 "
Cubic Feet, .	1,467,205		255 = 132 "	Cubic Feet, .	721,562		172 = 75 "
						Total Flues,	427 = 207 "

Total Indirect Radiating Surface in Square Feet, 20,000 }
Total Direct Radiating Surface in Square Feet, 4,975 } 24,975.

1886		Outside Temperatures, Direction and Force of the Wind. 2 A. M.			7 A. M.			2 P. M.			9 P. M.			TEMPERATURES. Average outside temperature.	Average inside temperature.	RADIATORS. Radiating surface used.	Radiating surface not used.	COAL. Nut and slack coal consumed.	COST. Fuel for each day, $1.50 per ton.
Feb.	1	18°	S.W.	Light.	15°	S.W.	Light.	18°	W.	Mod.	14°	S.	Mod.	16¼°	71 11/12°	15,257	8,718	22,100	$18.71
"	2	16	W.	"	12	S.W.	Mod.	17	N.W.	Heavy	6	N.W.	Heavy	12¾	71 4/12	16,955	7,020	23,800	20.23
"	3	4	N.	Mod.	10	N.	"	15	N.	Mod.	4	N.	"	8¼	70 11/12	18,358	5,617	23,800	20.23
"	4	2	N.W.	"	4	N.E.	"	5	N.E.	"	2	N.	Mod.	3¼	70 11/12	20,909	3,066	25,500	21.68
"	5	B.Z.-4	N.W.	"	B.Z.-12	N.W.	"	2	N.W.	Heavy	6	N.W.	"	B.Z.-4	71 4/12	20,177	3,798	27,200	23 12
"	6	10	W.	"	11	W.	Heavy	19	S.W.	"	24	S.W.	"	16	72	17,849	6,126	23,800	20.23
"	7	28	W.	"	28	S.	Mod.	32	W.	Mod.	37	S.W.	Heavy	28¼	73 11/12	14,699	9,276	18,700	16.90
"	8	26	S.W.	Light.	24	S.	"	45	S.	"	40	S.W.	Mod.	33¼	72 4/12	13,412	10,563	20,400	17.34
"	9	38	S.	Mod.	32	S.	"	55	S.	"	42	S.E.	Light.	41¼	72 4/12	10,949	13,026	13,600	11.56
"	10	38	S.E.	Light.	30	E.	Light.	45	S.	"	49	S.	Mod.	40¼	72 7/12	9,836	14,139	13,600	11.56
"	11	46	S.	Mod.	45	S.	Mod.	54	E.	Light.	42	N.E.	"	46¼	71 4/12	9,632	14,343	13,600	11.56
"	12	42	N.E.	"	40	N.E.	"	46	S.W.	"	48	S.E.	Light.	44	71 4/12	9,632	14,343	13,600	11.56
"	13	40	S.E.	Light.	44	S.W.	"	36	S.W.	Heavy	36	S.W.	Gale.	39	72	10,322	13,653	13,600	11.56
"	14	36	S.W.	"	38	S.	Light.	41	S.W.	Light.	37	S.E.	Light.	38	72	10,844	13,131	11,900	10.11
"	15	36	E.	"	34	S.W.	"	34	N.	"	28	S.W.	"	33	71 4/12	11,105	12,870	17,000	13.61
"	16	25	S.E.	"	20	N.W.	Heavy	25	S.W.	Mod.	18	S.E.	Mod.	22	71 4/12	13,247	10,728	20,400	17.34
"	17	20	S.E.	Mod.	16	S.E.	Mod.	26	S.W.	"	30	S.W.	Light.	23	71 4/12	16,125	7,850	20,400	17.34
"	18	32	S.E.	"	28	W.	"	46	E.	Light.	40	S.	"	36¼	72 4/12	13,664	10,311	17,000	13.61
"	19	40	W.	"	40	S.	"	40	S.W.	"	32	S.W.	"	38	73 4/12	12,806	11,169	17,000	13.61
"	20	15	N.E.	Light.	14	N.W.	Gale.	20	N.W.	Mod.	10	N.W.	Mod.	14¾	69 7/12	17,363	6,612	22,100	18.71
"	21	13	N.W.	Mod.	15	S.	Mod.	25	S.W.	"	35	N.W.	"	22	71	17,624	6,351	20,400	17.34
"	22	20	N.E.	"	25	W.	Light.	30	S.W.	Light.	32	S.W.	"	26¼	72 7/12	14,177	9,798	22,100	18.71
"	23	35	S.W.	"	32	N.E.	Mod.	30	N.E.	"	25	W.	"	30¼	73 4/12	13,097	10,878	18,700	16.90
"	24	18	N.W.	"	8	N.E.	"	30	N.E.	Mod.	35	S.	Light.	22¼	72 4/12	13,652	10,323	20,400	17.34
"	25	40	W.	Heavy	40	S.W.	Light.	40	S.W.	Light.	30	W.	Heavy	37¼	70 4/12	13,880	10,095	18,700	16.90
"	26	20	N.W.	Gale	10	N.W.	Gale.	12	N.W.	Mod.	15	N.	"	14¼	71 8/12	17,585	6,390	23,800	20.23
"	27	12	N.W.	Heavy	7	N.W.	Heavy	14	N.W.	Light.	12	N.W.	Light.	11¼	69 4/12	19,889	4,086	25,500	21.68
"	28	8	N.W.	Light.	10	N.E.	Light.	15	N.W.	"	12	N.W.	"	11¼	73 4/12	19,703	4,272	22,100	18.71
													AVERAGES.	25°	72°	14,741	9,234	19,671	$16.72

Cost of fuel per hour for Six Buildings, $1.50 per ton = 70 cents.
" 1,000 Cubic Feet of Space warmed for 24 hours, 1.1 cents.
" Coal for each Degree Difference of Temperature, 1⅛ cents.
Pounds of Coal for each Degree Difference of Temperature, 17.4.

MISCELLANEOUS.

2,188,770 ÷ 24,975 = 88 cubic feet space per foot radiating surface.

3–70 H. P. Marine Drop Flue Boilers, using *Brightman Mechanical Stokers.*
Steam Supply Pipe, 12 inch; Return, 4 inch. Length Supply and Return Pipes, 2,500 ft.

The Brightman furnaces were also introduced with the sectional safety Mills boilers at Springfield, new Jail and House of Correction. From my record book of April 18, 1887, I take the following data:—

Evaporative test of 14 section No. 6 Mills boiler, run of 10 hours, *with Brightman mechanical stoker*, using bituminous *nut and slack coal.*

Heating surface in square feet	858
Grate surface in square feet	16
Ratio of heating surface to grate surface	53.6 to 1
Mean temperature of steam (30 lbs.)	274°
Mean temperature of feed water	40°
Water evaporated in pounds	18,452
" " " " per lb. of coal, gross	9.8
" " " " from and at 212°	21,958
" " " " per square foot grate per hour .	115.6
" " " " per square foot of heating surface .	2.2
" " " " from and at 212° per lb. coal . .	11.14
" " " " from and at 212° per lb. combust. .	12.5
Total coal used in pounds	1,880
Ashes and waste in pounds (= 7 per cent)	125
Total combustible in pounds	1,755
Pounds of coal per square foot of grate per hour	115.5

Horse power of generator, 69.7 (31½ lbs. of water per h. p.).

Evaporative test of 14 section No. 6 Mills boiler, run of 5 hours, *flat horizontal grate, hand firing,* burning bituminous nut and slack coal.

Heating surface in square feet	858
Grate surface in square feet (25 per cent more than above) . .	20
Ratio of heating surface to grate surface	33 to 1
Mean temperature of the steam (30 lbs.)	274°
" " of flue	540°
" " of feed water	40°
Total coal burned in 5 hours (pounds)	880
Per cent ashes and waste "	8.6
Total combustible "	810
Pounds of coal per square foot of grate per hour	8.8
Water evaporated in pounds	706
" " " " per lb. of coal, gross	8.03
" " " " per lb. from and at 212°	8.41
" " " " per square foot of grate per hour .	54
" " " " per square foot heating surface . .	1.6
" " " " from and at 212° per lb. of coal . .	9.56
" " " " from and at 212° per lb. of combust.,	10.4

Horse power of generator, 53.4 (31½ lbs. of water per h. p.).

CHAPTER X

Petroleum—Production and Transportation.*

THE word "petroleum" means rock oil, and in its present form it is adopted from the Latin into the English. Its equivalents in German are *erdöl* (earth oil) and *steinöl* (stone oil); in French and other languages of Southern Europe the word is *pétrole*, equivalent to petroleum.

Bitumen. Petroleum is one of the forms of bitumen, and cannot be discussed historically except in connection with its other forms. These are — Solid: Asphaltum. Semi-fluid: Maltha. Fluid: Petroleum. Volatile: Naphtha. Gaseous: Natural gas.

Solid bitumen is to be distinguished from coal in the manner of its occurrence, and also in the action of certain solvents which dissolve it, but have no action upon coal.

Bitumen has been applied to the use of man from the dawn of history.

The semi-fluid bitumen was used in the construction of the cities of Nineveh and Babylon to cement bricks and slabs of alabaster; and the grand mosaic pavements and beautifully inscribed slabs used in the palaces and temples of those ancient cities, many of which were of enormous size, were fastened in their places with this material. It was also used to render cisterns and silos for the preservation of grain water-tight, and some of these structures of unknown antiquity are still found intact in the ancient cities of Egypt and Mesopotamia.

The Pitch Lake of Trinidad is the most extensive known deposit of asphaltum. The lake is about three miles in circumference, and is described as a mass of asphaltum, sloping to the northern sea coast. Although firm enough to bear a team of horses, it is still somewhat plastic, and it appears to be in motion towards certain points that act as vortices, as the trunks of trees disappear and after a time emerge at some distance from the point at which they sunk.

Small lakes and streams of water abounding in fish are described as distributed over its surface, with numerous islands covered with tropical verdure. The asphaltum is exported from the island to the United States and Europe, where it is used for the preparation of roofing materials, and in the production of mastic pavements.

*Census Official Report, 1885.

The Occurrence of Petroleum in North America was noticed by the earliest explorers, as the Indians dwelling in the vicinity of the Great Lakes applied it to several purposes, and this brought it to the attention of those who went among them. Its presence as an oily scum on the surface of ponds and streams had long been known, and among the Indians this "rock oil" was highly appreciated as a vehicle for mixing their war paint, and for anointing their bodies; in later years it was gathered in a rude way by soaking it up in blankets, and sold at a high price for medicinal purposes only, under the name of "Seneca Rock Oil," "Genesee Oil," "Indian Oil," etc.

The French commander of Fort Duquesne in the year 1750 writes as follows to General Montcalm:—

"I would desire to assure you that this is a most delightful land. Some of the most astonishing natural wonders have been discovered by our people. While descending the Alleghany, some fifteen leagues below the mouth of the Conewanga and three above the Venango, we were invited by the Chief of the Senecas to attend a religious ceremony of his tribe. We landed and drew up our canoes on a point where a small stream entered the river. Gigantic hills begirt us on every side. The tribe appeared unusually solemn. We marched up the stream about half a league, where the company, a band, it appeared, had arrived some days before. The great chief then recited the conquests and heroism of their ancestors. The surface of the stream was covered with a thick scum, which, upon applying a torch at a given signal, burst into a complete conflagration. At the sight of the flames the Indians gave forth the triumphant shout that made the hills and valleys re-echo again. Here, then, is revived the ancient fire-worship of the East; here, then, are the children of the Sun!"

Late in the last century springs of petroleum were noticed in West Virginia, in Ohio, and in Kentucky, as explorers began to penetrate the country west of the Alleghany Mountains.

The date of its discovery as an important factor in the useful arts and as a source of enormous national wealth was about 1854. In the year named, a certain Mr. George H. Bissell, a native of Hanover, N. H., accidentally met with a sample of the "Seneca Oil," and, being convinced that it had a value far beyond that usually accorded to it, associated himself with some friends and leased for ninety-nine years some of the best oil springs near Titusville, Pa. This lease cost the company $5,000, although only a few years before a cow had been considered a full equivalent in value for the land. The original prospectors began operations by digging collecting ditches, and then pumping off the oil which collected on the surface of the water.

But not long after this first crude attempt at oil gathering, the Pennsylvania Rock Oil Company was organized, with Professor B. Silliman, of Yale College, as its President, and a more intelligent method was introduced into the development of the oil-producing formation. In 1858 Colonel Brake, of New Haven, was employed by the Pennsylvania company to sink an artesian well, and, after considerable preparatory work, on Aug. 28, 1859, the first oil vein was tapped at a depth of 69½ feet below the surface; the flow was at first 10 barrels a day, but in the following September this increased to 40 barrels daily.

The popular excitement and the fortunes made and lost in the years following the sinking of the initial well are a matter of history, with which we have here nothing to do.

It is sufficient to say that a multitude of adventurers were drawn by the "oil craze" into this late wilderness, and the sinking of wells extended with unprecedented rapidity over the region near Titusville, and from there into more distant fields.

By June 1, 1862, 495 wells had been put down near Titusville, and the daily output of oil was nearly 6,000 barrels, selling at the wells at from $4 to $6 per barrel.

But the tapping of this vast subterranean storehouse of oleaginous wealth continued, until the estimated annual production was swelled from 82,000 barrels in 1859 to 24,385,966 barrels in 1883; in the latter year 2,949 wells were put down, many of them, however, being simply dry holes.

The total number of wells in the Pennsylvania oil regions cannot be given. In the years 1876–1884 inclusive, 28,619 wells were sunk; this is an average of 3,179 per year. During the same period 2,507 dry holes were drilled, at an average cost of $1,500 each.

The total output of oil in the Pennsylvania regions, between 1859 and 1883, is estimated at about 234,000,000 barrels—enough oil to fill a tank about 10,000 feet square, nearly two miles to a side, to a depth of over 13½ feet.

DEPOSITS OF PETROLEUM IN THE UNITED STATES.

Pennsylvania. In the twenty-one years that oil mining has been the principal industry of Northwestern Pennsylvania, there have been discovered, besides numerous minor deposits, three great basins of petroleum, known among oil men as the Venango, the Butler, and the Bradford districts. The first centres on Oil Creek, Venango county; the second on Beaver Creek, Butler county; and the third covers an area of about sixty thousand acres in the northeastern corner of McKean county, N. Y.

New York. In 1865 Jonathan Watson drilled a well in Ontario county, five miles east of Canandaigua Lake, and found there a good rock oil, plenty of gas, and a production of about five barrels of oil daily. A line drawn from this point west to Lake Erie and another south to the Pennsylvania line would include all the territory in the state of New York over which oil or gas has been obtained by boring; and along the shores of Lake Erie, from the state line to Buffalo, at almost any point natural gas can be obtained by artesian borings.

Ohio and West Virginia. There are three localities in Ohio that have yielded petroleum from an early date. These are the neighborhood of Mecca, in Trumbull county; the neighborhood of Belden, in Lorain county, and Washington county.

"The White Oak Anticlinal" of West Virginia extends from Newell's Run, a tributary of the Little Muskingum River, in Newport township, Washington county, Ohio, to Roane county, West Virginia, passing through Pleasants, Ritchie, Wood, and Wirt counties of the latter state.

Oil is also found in commercial quantities and over considerable areas in the states of Kentucky, Tennessee, and California, and occurs in Indiana, Illinois, Missouri, Alabama, Michigan, Kansas, and Louisiana.

There are five foreign oil fields which have attracted attention and which have produced more or less oil in commercially valuable quantities. These are the region of the Caucasus, Galicia, Canada, Japan, and Peru. Of these, the first mentioned is altogether the most important, as far as present information indicates. Next may be placed Canada.

The Russian districts lie in two fields, one at each extremity of the Caucasus. The western, on the Black Sea, is the Kouban; the eastern is the Baku district, on the peninsula of Apscheron, extending into the Caspian Sea, and on which the city of Baku now stands. The area of the Kouban district is about two hundred and fifty square miles.

The petroleum fields of Walachia, Moldavia, and Galicia lie upon the southern, eastern, and northern flanks of the mountain system that incloses Hungary from Russia and the plains of the Danube.

The productive oil fields of Canada lie in the county of Lamberton, in the western part of the province of Ontario.

Flowing wells were struck here in 1862, and some of them proved the most prolific on record, rivaling those of the region around Baku. These great wells were exceptional, and the average yield has been small. The region over which borings have proved the existence of oil in paying quantities is about fifty miles north and south, and about one hundred miles east and west, and within this range Petrolia, Bothwell, and Oil Springs have produced nearly all the oil.

The petroleum of Canada contains sulphur and is difficult to refine, but its production has been fostered, and it supplies a large demand throughout the British provinces.

The Foreign Production of Petroleum. The Russian "Oil Belt" may be traced, at intervals more or less remote, from the island of Schily-Khany, near the eastern shore of the Caspian Sea, westward over the promontory of Apscheron, and, following the line of the Caucasian Mountains, into the valley of the river Kouban, which empties its waters by a lagoon into the Black Sea; thence it may be traced in the same general direction across the Crimea and to the oil fields of Galicia in Austria.

The belt is actively worked in the Crimea, in the valley of the Kouban, and on the promontory of Apscheron, near the city of Baku. It is only at the latter point, however, that the product is sufficiently large to induce the gathering of statistics. At all other points the petroleum produced, whether gathered from springs or obtained by well-boring, is entirely absorbed by local consumption.

As the average yield of refined petroleum from Apscheron crude is about one third, we may estimate the total crude product of that field for the year 1879 at 2,500,000 barrels, or 6,580 barrels per day. This oil is all consumed in Russia, a very little manufactured for lubricating excepted.

The largest well ever found had been producing for six years in 1879, and had yielded during that time an average of 1,200 barrels per day — a production much in excess of any Pennsylvania well.

The product of the Apscheron field declined about 9 per cent in the first half of the year 1880; and by the end of the year the decline was so serious, that the price which had ruled for two years, with little variation, at 24 cents per barrel, advanced in the autumn to between \$1 and \$2 per barrel; but in 1881 production was so increased that the price fell in August to 8 cents per barrel of 40 gallons.

Although illuminating oils manufactured in Russia from the native crude product compare favorably with American oils, the latter have nevertheless been yearly imported into Russia, though in diminishing quantity; but the fact that these imports still continue seems to need explanation, in view of the heavy duty of 9 cents per gallon imposed upon American oil.

The gravity of the Baku oil ranges from 26° to 36° B., there being very little of the latter grade; and the gravity of oil taken from the pipe-line tanks, where the product of different wells is mixed, is about 30° B. This mixed oil gives a yield of about 33 per cent illuminating oil, and the residuum is used for fuel. No other fuel is used by steamers on the Caspian Sea. Many of the steamers on the Volga also use it.

The Influence of Petroleum upon Civilization. "The earthen lamps of Burmah and the rude lamps of Galicia were all of them little better than fagots or pitch knots. It is the advent of refined petroleum, at comparatively low prices, that has practically lengthened the duration of human life and has added vastly to the social enjoyment of mankind, not only among highly civilized peoples, but among the semi-civilized and savage nations; in fact, wherever the white wings of commerce can transport it, there it has gone; and, more, its light has penetrated even the solitudes of the eastern deserts and the forests of both hemispheres."

In 1869 M. Felix Foucou published an article in the *Revue des Deux Mondes* that is especially interesting in this connection.

He says: "In the domain of the useful arts each age reveals characteristic tendencies. In the last century mankind had need to clothe itself cheaply. It was this that made the fortune of Arkwright, and the machine spinners, the sudden prosperity of Manchester and the continental cities which imported the new method of labor. The 19th century has wished for light, both in the birch-bark wigwam of the Indian and the mud cabin of the poor Ruthenian of Galicia."

The introduction of the most modest lamp gives activity to family life in prolonging the evening's labors. France has largely contributed to this result. The invention of Argand, which was the first progressive step in advance of the smoky candle wick of ancient times, arose painfully on the eve of the French revolution; the Carcel lamp and gas are of but yesterday. A crowd of obscure inventors have with unremitting labor perfected the mechanism of lamps in order to escape the costly necessity of burning vegetable oils. These experiments, many of which were undertaken under the Monarchy, prepared the way for the success of petroleum; unfortunately they came at a moment when it was premature to dream that illumination by mineral oil should become universal.

The material was at first wanting; chemistry had not as yet furnished a means of extracting those precious substances from the schists with which they were found associated at many points; and science had not yet shown the part that liquid petroleum was destined to play — of which a great many springs were then known. It is to the Americans that the merit belongs of having given this last right of citizenship among the industries. The native talent that led them to regard the useful aspect of everything, above all the feverish but patient activity, seconded so well by a happy temperament, has served them marvelously on this occasion. The French chemist Seligue gave them the first experiments in the basin of Autun, about the year 1832, by distilling on an industrial scale the schists which abound in that part of France.

The average duration of the profitable production of an oil well is very uniformly estimated as *five years*, but this period is subject to very great variations. The wells in the Colorado district northeast of Titusville have been pumped for twelve years, and have yielded constantly more than enough to pay expenses. In the White Oak district of West Virginia the Scott and Scioto wells, drilled in 1865, were being pumped in 1880.

On the contrary, the Cole Creek division of the Bradford field had all been drilled over since 1879, and some of the wells were abandoned before June 4, 1881; while at the same date wells were flowing near Tarport, in the same field, that were drilled in 1875. As a general rule it may be said that the nearer wells are to each other on a given piece of property, the sooner they will become unprofitable.

The proximity of other outlets appears to determine the duration of the flow of oil springs and wells. The spring in the island of Zante is known to have flowed *two thousand years*.

The Beatty well in Wayne county, Kentucky, drilled in 1819, is still flowing, there being no other well near it

The American well flowed oil in large quantities from 1830 to 1860; but, after the drilling of other wells in the neighborhood, the yield fell off, and finally ceased altogether. It is therefore impossible for any producer controlling a small area to keep his oil beneath the surface.

Jonathan Watson has, in his experience, known water to run into a well from another half a mile distant, and in another instance red paint was put into one well and pumped out of another at about the same distance.

The drilling of fourteen-hundred-foot wells was worth during the census year 60 cents per foot. The general estimate given by producers of large experience is that the total cost of fourteen-hundred-feet wells is about $2,000.

Of the oil which runs to waste no estimate approaching accuracy can be made. Mr. Welch says in his report of August, 1879:—

"It is well known that a large amount of oil went to waste in July on account of inability to take care of it. Early in the month there may have been five or six thousand barrels lost per day in this way, and considerable loss continued most of the time during the month."

In his report of June, 1880, he says:—

"The large amount of oil being lost in the Bradford district makes estimates on the production an uncertain thing. The amount *lost* now is being estimated as high as ten and *twelve thousand barrels daily*."

PRODUCTION OF THE THIRD SAND OIL, SHOWING THE OIL WASTED AND BURNED, DURING THE CENSUS YEAR 1880.

	Barrels.
1. Pipe line receipts	22,628,286
2. Gain in well stocks	446,855
3. *Oil run to waste*	275,000
4. *Oil burned* outside of well stocks and pipe lines	60,000
5. "Dump oil" and oil run to private lines	578,670
Total	23,988,791

There were produced, other than the third sand oil, 365,273 barrels, making the total production for the census year 24,354,064 barrels.

"While it is not probable that the deposits of petroleum within the crust of the earth are being practically increased at the present time, there is reason to believe that the supply is ample for an indefinite period. When prophecy, indulged in even by the most sagacious observers of the longest experience, proves so futile, I think I am warranted in expressing the opinion that, as regards the future supply of petroleum, the drill alone gives ample testimony. Yet this fact is worthy of the most serious consideration: The production of petroleum at present *is wasteful in the extreme.* No thoughtful person can escape the conviction that future generations will want what this generation is destroying to no purpose. 'After us, the deluge' is written all over the oil region in the destruction of forests and in the waste of the oil itself."

The Paraffine Oil Industry. Mr. James Young, of Glasgow, perfected the process, and established in 1847 in Derbyshire a vast manufactory for treating the English minerals, incomparably richer than those of France, and known under the name of boghead and cannel coal.

In a few years this establishment took on an extraordinary development, and yielded its projectors several hundred thousand francs of revenue. The prospect of such profits so soon realized placed this manufacture in a reputable position.

It extended to the United States in 1854, where it was employed on the Scotch boghead, as well as on several other indigenous schists. In 1860 there were in America sixty-four manufactories of schist oil. The discovery of abundant reservoirs of petroleum suddenly arrested this growing industry, ruined a large number of manufactories, and led their projectors to change them into refineries of petroleum, that substance being much richer in illuminating material than boghead or cannel coal.

At the date, 1860, at which petroleum was first an article of commercial importance, paraffine and paraffine oils were being produced in the United States and Great Britain from the so-called boghead coal, albertite and grahamite, together with several rich cannel coals.

The deposit of the boghead mineral was worked out in 1872, since which time the extensive paraffine oil works of Scotland have been run on shale. On the continent of Europe, in Saxony, Thuringia, and Austria, a very extensive and valuable industry is conducted with shale and brown coal as the raw material. In the United States, besides our deposits of cannel and bituminous coals of enormous extent, we have thousands of square miles of shales, that will furnish millions of barrels of distillate for use, after our two hundred thousand square miles of petroleum fields shall have been exhausted.

The historical development of the oil industry may be summed up as follows: In many regions and for immemorial periods, petroleum gathered from natural springs and dug wells has been used for medicine, and in a rude way as an illuminating agent.

In China artesian wells have been bored for brine and for natural gas, and the latter was used to boil brine for centuries before the Christian Era. In the United States artesian borings made for brine had furnished petroleum in enormous quantities thirty or forty years before any use was known for such a supply. The development of the coal-oil industry between 1850 and 1860 led to experiments upon petroleum as a substitute for the crude oil obtained from coal, and with the success of those experiments (1859) came the demand for petroleum, which led to Drake's attempt to obtain oil directly by boring.

The success attending the oil industry in Pennsylvania during the first four years of its existence, led to the organization of companies all over the world for the purpose of drilling test wells wherever springs of petroleum were accessible. In some localities they were successful, in others only partially so; while in the majority of instances they were failures, or were found inferior to the primitive dug wells.

The continuously increasing and enormous production of the United States, and the consequent depreciation in value of all the products manufactured from petroleum, has led to the almost complete control of that trade by American manufacturers, Galicia and the Caucasus being at the present time their only competitors, and that to a very limited extent."

Since the manufacture of petroleum by distillation was commenced, there have been several separate products used for illuminating purposes. Most of the illuminating oils have been called "kero[illegible] a name which was originally adopted as a trade mark by [illegible] engaged in the manufacture of coal oils, but which soon [illegible] became a designation applied to a certain class of oils used i[illegible] lamp.

Refined Petroleum. The present method of distillation was invented about 1865. This plan consists in a slow and repeated distillation, which produces destructive distillation of the medium and heavy oils, converting them into oils of a density suitable for illumination with a production of gaseous products and the deposition of carbon. In order to accomplish this result, after that portion of the distillate suitable for illumination has been separated, the fires are slackened, and the vapors of the heavy oils, as they rise into the dome of the still, are allowed to condense and drip back on the heavy oil below, which has meantime been heated to a temperature above the boiling point of the oil dripping upon it. This practically superheats the vapors of the oil and produces decomposition. The effect of distillation under pressure is practically the same; the oils are distilled at a temperature above their normal boiling points.

By this process of distillation the petroleum can be converted into naphtha, illuminating oil, and coke, with a certain amount of gas either escaping into the atmosphere, or being burned. The illuminating oils may be collected into one receptacle and be made of uniform grade, or that proportion of petroleum suitable for purposes of illumination can be separated from that produced by destructive distillation, thus furnishing two grades of illuminating oil quite different in composition and quality; the light oils in the crude petroleum being superior to those produced by the decomposition of the heavier portions of the oil. This method of distillation had been successfully pursued in treating the distillates of coal before the introduction of petroleum, but it was not generally applied to the treatment of petroleum in very large stills, until about the time indicated.

Its successful introduction was, however, the result of an accumulated experience, not only in the distillation, but quite as much in the subsequent treatment of the oils with acids and alkalies, especial regard being had to the temperature while undergoing treatment.

The largest petroleum refineries in the country are at tide-water at Hunter's Point and New Town Creek, L. I.; Bayonne, N. J.; Point Breeze, below Philadelphia, and at Thurlow, below Chester, on the Delaware; and near Baltimore, Md. At Bayonne, N. J., the Standard and Ocean refineries have piers one thousand feet in length, with sufficient water to float the largest ships, and facilities for loading from six to seven thousand barrels of oil per day.

Petroleum is generally destructive to animal life, and particularly to insect life. Hildebrant, an African traveler, advises smearing the face and hands with petroleum to protect them from mosquitoes. He also advises the use of petroleum on horses and cattle as a protection from the deadly Dondorobo gad-fly.

It is, however, as a material forming the basis of ointments that the preparations of petroleum have obtained a strong hold on the medical profession. The preparations, cosmoline, vaseline, petrolina, etc., which are all essentially the same thing, have now a permanent place in the materia medica.

PRODUCTS OF THE MANUFACTURE OF PETROLEUM AND THEIR VALUE DURING THE CENSUS YEAR 1880.

Articles.	Barrels.	Value.
Rhigolene and cymogene	5,868	$29,117
Gasoline	289,555	1,128,166
Naphtha	1,212,626	1,833,395
Illuminating oil	11,002,249	36,839,613
Mineral sperm	16,544	202,725
Reduced petroleum for cylinders	26,018	371,020
Reduced petroleum for journals	204,841	1,024,017
Deodorized lubricating oils	70,415	611,572
Paraffine oil	79,465	408,023
Residuum	229,133	297,529
	13,136,714	
Paraffine wax	7,889,626 (lbs.)	631,944
Miscellaneous products		328,097
Total		$43,705,218

THE YEARLY PRODUCTION, AVERAGE YEARLY PRICE, AND VALUE OF ALL OIL PRODUCED FROM 1860 TO DEC. 31, 1880, BOTH INCLUSIVE.

Year.	Number of Barrels.	Average Price per Barrel.	Amount.
1860	500,000	$9.60	$4,800,000.00
1861	2,113,609	.49	1,035,668.41
1862	3,056,690	1.05	3,209,524.50
1863	2,611,309	3.15	8,225,623.35
1864	2,116,109	9.87	20,896,576.37
1865	2,497,700	6.59	16,459,843.00
1866	3,597,700	3.74	13,455,398.00
1867	3,347,300	2.41	8,066,993.00
1868	3,646,117	3.62	13,217,174.12
1869	4,215,000	5.63	23,730,450.00
1870	5,260,745	3.89	20,503,753.63
1871	5,205,341	4.34	22,591,179.94
1872	5,890,248	3.64	21,440,502.72
1873	9,890,964	1.83	18,100,464.12
1874	10,809,852	1.17	12,647,526.84
1875	8,787,506	1.35	11,863,133.10
1876	8,968,906	2.56	22,982,821.62
1877	13,135,771	2.42	31,788,565.82
1878	15,163,462	1.19	18,044,519.78
1879	20,041,581	.85	17,210,707.68
1880	26,032,421	.94	24,600,637.84
Total	156,888,331		$334,871,063.84

Average price per barrel for 21 *years,* $2.12.

The Transportation of Petroleum to the Seaboard.* While Englishmen and Americans have been alike interested in the late project for forcing water by a pipe line over the mountainous region lying between Suakim and Berber, in the far-off Soudan, few men of either nation have any proper comprehension of the vast expenditure of capital, natural and engineering difficulties overcome, and the bold and successful enterprise which has brought into existence far greater pipe lines in our own Atlantic States. We refer to the lines of the National Transit Company, which have for a purpose the economic transportation of crude petroleum from Western Pennsylvania to the sea coast at New York, Philadelphia, and Baltimore, and to the lakes at Cleveland and Buffalo.

The problems in hydraulics presented in the construction and management of pipe lines, particularly those lines which may be denominated trunk lines out of the oil regions, are many and intricate, and required great courage on the part of those who projected the first lines to meet and surmount them. These men had only the quite different experience met in laying pipes for water to guide them. *These* problems dealt with a homogeneous fluid, flowing in pipes, laid permanently on curves of large diameter, flowing slowly under a slow pressure, and delivered slowly. The water pressure seldom exceeded from forty to fifty pounds per square inch. The *pipe-line problems* dealt with a fluid varying in density and pressure with the temperature, flowing easily in summer and with difficulty in winter through pipes of small diameter, laid hurriedly, and frequently changed, often on sharp curves or at right angles, for rapid movement and delivery, and at high pressures to compensate in part for the friction due to long distances and rapid transmission, and small diameter of pipe, as well as at much greater elevations than are found in water pipes.

As long as oil could be sold at the wells at from $4 to $10 per barrel, the cost of transportation was an item hardly to be considered, and railroad companies multiplied, and waged a bitter war with each other in their scramble after the traffic. But as the production increased with rapid strides, the market price of oil fell with a corresponding rapidity, until the quotations for 1864 show figures as low as 50 to 60 cents per barrel for the crude product at Oil City.

In December, 1865, the freight charge per barrel for a carload of oil from Titusville to New York, and the return of the empty barrels, was $3.50. To this figure was added the cost of transportation by pipe line from Pithole to Titusville, $1; cost of barreling, 25 cents; freight to Corry, Pa., 80 cents; making a total cost of a barrel of crude oil in New York $5.55. In January, 1866, the barrel of oil in New York

* *Scientific American Supplement*, July 11, 1883.

cost $10.40, including in this figure, however, the government tax of $1 and the price of the barrel, $3.25.

The question of reducing these enormous transportation charges was first broached apparently in 1854, when a writer in the *North American*, of Philadelphia, outlined a scheme for laying a pipe line down the Allegheny River to Pittsburg. This project was violently assailed by both the transportation companies and the people of the oil region, who feared that its success would interfere with their then great prosperity. But short pipe lines connecting the pipes with the storage tanks and shipping points grew apace and prepared the way for the vast network of the present day, which covers this region and throws out arms to the ocean and the lakes.

Among the very first, if not the first, pipe lines laid, was one put down between the Sherman well and the railway terminus on the Miller Farm. It was about three miles long, and designed by a Mr. Hutchinson; he had an exaggerated idea of the pressure to be exercised, and at intervals of fifty to one hundred feet he set up air chambers ten inches in diameter. The weak point in this pipe, however, proved to be the joints; the pipes were of cast iron, and the joint leakage proved to be so great that little, if any, of the oil ever reached the end of the line, and the scheme was abandoned in despair.

In connection with this question of oil transportation, a sketch of the various methods, other than pipe lines, adopted in Pennsylvania may not be out of place. We are mainly indebted to Mr. S. F. Peckham, in his article on petroleum and its products in the United States Census reports of 1880, for the information relating to the tank cars immediately following.

Originally the oil was carried in 40 and 42 gallon barrels made of oak and hooped with iron; early in 1866, or possibly in 1865, tank cars were introduced. These were at first ordinary flat cars on which were placed two wooden tanks shaped like tubs, each holding about 2,000 gallons.

On the rivers bulk barges were after a time introduced on the Ohio and the Allegheny. At first these were rude affairs, and often of inadequate strength; but as now built they are 130 x 22 x 16 feet in their general dimensions, and divided into eight compartments, with water tight bulk-heads. They hold about 2,200 barrels.

In 1871, iron tank cars succeeded those of wood, with tanks of varying sizes, ranging from 3,856 to 5,000 gallons each.

These tanks were cylinders, 24 feet, 6 in. long, and 66 in. in diameter, and weighed about 4,500 pounds. The heads were made of 5-16 in. flange iron, the bottom of 1-2 in., and the upper half 3-16 in.

In October, 1865, the Oil Transportation Company completed and tested a pipe line 32,000 feet long; three pumps were used upon it, two at Pithole and one at Little Pithole. July 1, 1876, the pipe-line owners held a meeting at Parker's to organize a pipe-line company to extend to the seaboard under the charter of the Pennsylvania Transportation Company, but the scheme was never carried out. In January, 1878, The Producers' Union organized for a similar seaboard line, and laid pipes; but they never reached the sea, stopping their line at Tammanend, Pa. The lines of the National Transit Company, illustrated in our map, were completed in 1880–1881; and this company, to which the United Pipe Lines have been transferred, is said to have $15,000,000 invested in plant for the transport of oil to the tide water.

The National Transit Company was organized, under what is called the Pennsylvania Company act, about four years ago, and succeeded to the properties of the American Transit Company, a corporation operating under the laws of Pennsylvania.

Since its organization, the first-named company has constructed and now owns the following systems: —

* The line from Olean, N. Y., to Bayonne, N. J., and to Brooklyn, N. Y., of about 300 miles. The Pennsylvania line, 280 miles long, from Colegrove, Pa., to Philadelphia. The Baltimore line, 70 miles long, from Millway, Pa., to Baltimore, Md. The Cleveland line, 100 miles long, from Hilliards, Pa., to Cleveland, O. The Buffalo line, 80 miles long, from Four Mile, Cattaraugus county, N. Y., to Buffalo, and the line from Carbon Center, Pa., Butler county, to Pittsburg, 60 miles in length.

This amounts to a total of 880 miles of main pipe alone, ranging from 6 inches to 4 inches in diameter; or, adding the duplicate pipes on the Olean, N. Y., line, we have a round total of 1,330 miles, not including loops and shorter branches and the immense network of the pipes in the oil regions proper.

A general description of the longest line will answer for all, as they differ only in diameter of pipe used and power of the pumping plant. As shown on the map, this long line starts at Olean, near the southern boundary of New York state, and proceeds by the route indicated to tide water at Bayonne, N. J., and by a branch under the North and East rivers and across the upper end of New York City to the Long Island Refineries. This last-named pipe is of unusual strength, and passes through Central Park; few of the thousands who daily frequent the latter spot being aware of the yellow stream of crude petroleum that is constantly flowing beneath their feet.

* See following map of pipe lines, page 142.

The following table gives the various pumping stations on this Olean, N. Y., line, and some data relating to distances between stations, and elevations overcome.

Pumping Stations.	Miles between Stations.	Elevation above Tide. Feet.	Greatest Summit between Stations. Feet.
Olean	.....	1,490	.....
Wellsville	28.20	1,510	2,490
Cameron	27.91	1,042	2,530
West Junction	29.70	911	1,917
Catatonk	27.37	869	1,768
Osborne	27.99	1,092	1,539
Hancock	29.86	922	1,873
Cochecton	26.22	748	1,854
Swartwout	28.94	475	1,478
Newfoundland	29.00	768	1,405
Saddle River	28.77	35	398

On this line two 6-inch pipes are laid the entire length, and a third 6-inch pipe runs between Wellsville and Cameron, and about half way between each of the other stations, "looped" around them. The pipe used for the transportation of oil is especially manufactured to withstand the great strain to which it will be subjected, the most of it being made by the Chester Pipe and Tube Works, of Chester, Pa., the Allison Manufacturing Company, of Philadelphia, and the Pennsylvania Tube Works, of Pittsburg, Pa. It is lapwelded wrought-iron pipe, of superior material, and made with exceeding care and thoroughly tested at the works. The pipe is made in lengths of 18 feet, and these pieces are connected by threaded ends and extra strong sleeves. The pipe thread and sleeves used on the ordinary steam and water pipe are not strong enough for the duty demanded of the oil pipe. The socket of a 4-inch steam or water pipe is from 2½ to 2¾ inches long, and is tapped with 8 standard threads to the inch, straight or parallel to the axis of the pipe; with this straight tap only 3 or 4 threads come in contact with the socket threads, or in any way assist in holding the pipe together. In the oil pipe, the pipe ends and sockets are cut on a taper of ¾ inch to 1 foot, for a 4-inch pipe, and the socket used is thicker than the steam and water socket, is 3¾ inches long, and has entrance for 1⅝ inches of thread on each pipe, and tapped with 9 standard threads to the inch. In this taper socket you have iron to iron the whole length of the thread, and the joint is perfect and equal by test to the full strength of the pipe.

Up to 1877 the largest pipe used on the oil lines was 4-inch, with the usual steam thread; but the joints leaked under pressure, 1,200 pound to the square inch being the maximum that the 8-inch thread would stand.

This trouble has been remedied by the 9-inch thread, taper-cut pipe of the present day, which is tested at the mill to 1,500 pounds pressure; while the average duty required is 1,200 pounds. As the iron used in the manufacture of this line pipe will average a tensile test strain of 55,000 pounds per square inch, the safety factor is thus about one sixth.

The line pipe is laid between the stations in the ordinary manner, excepting that great care is exercised in perfecting the joints. No expansion joints or other appliances of like nature are used on the line as far as we can learn; the variations in temperature being compensated for in exposed positions, by laying the pipe in long horizontal curves. The usual depth below the surface is about three feet, though in some portions of the route the pipe lies exposed for miles directly upon the surface. As the oil pumped is crude oil, and this as it comes from the wells carries with it a large proportion of brine, freezing in the pipes is not to be apprehended. The oil, however, does thicken in very cold weather, and the temperature has a considerable effect on the delivery.

The pumping stations are substantial structures of brick roofed with iron. The boiler-house is removed some distance from the engine-house for greater safety from fire; the building, about 40 x 50 feet, contains from 6 to 7 tubular boilers, each 5 x 14 feet and containing 80 3-inch tubes. The pump-house is a similar brick structure about 40 x 60 feet, and contains the battery of pumping engines to be described later. At each station are two iron tanks, 90 feet in diameter and 30 feet high; into these tanks the oil is delivered from the preceding station, and from them the oil is pumped into the tanks at the next station beyond. The pipe system at each station is simple, and by means of the "loop lines" above mentioned the oil can be pumped directly around any station if occasion should require it.

The pumps used on all these lines are the Worthington compound, condensing, pressure pumping engines. The general characteristics of these pumps are independent plungers with exterior packing, valve boxes subdivided into separate small chambers capable of resisting very heavy strains, and leather-faced metallic valves with low lift and large surfaces.

These engines vary in power from 200 to 800 horse-power, according to duty required. They are in continuous use, day and night, and are required to deliver about 15,000 barrels of crude oil per 24 hours, under a pressure equivalent to an elevation of 3,500 feet.

The Pennsylvania line has a single 6-inch pipe 280 miles long, with 6 pumping stations, as shown in the map, and groups of shorter lines,

a loop extending from the main line to Milton, Pa., a point for shipping on the cars. At Millway, Pa., a 5-inch pipe leaves the Pennsylvania line and runs to Baltimore, a distance of 70 miles, and is operated from the first-named station alone, there being no intermediate pumping station.

The Cleveland pipe, 100 miles long, is 5 inches in diameter, and has upon it 4 pumping stations. It carries oil to the very extensive refineries of the company at the terminal on Lake Erie.

The Buffalo line is 4 inches in diameter and 70 miles long; it has a pumping station at Four Mile and at Ashford (omitted on the map).

The Pittsburg line is 4 inches in diameter and 60 miles long; it has pumping stations at Carbon Centre and at Freeport.

A very necessary and remarkably complete adjunct to the numerous pipe lines of this company is an independent telegraphic system extending to every point on its widely diverging lines. The storage capacity of the National Transit Company's system is placed at 1,500,000 barrels, and this tankage is being constantly increased to meet the demands of the producers.

As showing the extent of the sea-coast transportation of petroleum, we should mention that the statistics of 1884 show a total of crude equivalent exported from the United States in that year equaling 16,661,086 barrels of 51 gallons each; this is a daily average of 42,789 barrels.

The enterprise has been thus far a great engineering success, and the oil delivery is stated on good authority to be within 2 per cent of the theoretical capacity of the pipes.

From a commercial standpoint the ultimate future of the undertaking will be determined by the lasting qualities of wrought-iron pipe buried in the ground and subjected to enormous strain; time alone can determine this question. For map of pipe lines to seaboard, see page 142.

*THE GEOLOGY OF THE OIL AND COAL REGIONS.

"The most interesting feature of the geology of the Barren Coal Measures is their oil-bearing sands. The Morgantown sandstone is the first oil sand of the Dunkard's Creek oil region; and yet it lies only about 150 feet beneath the Pittsburg coal bed; and its outcrop, 50 feet thick, can be seen from the windows of the Monongahela House, running along the bluffs on the opposite side of the river. The Mahoning sandstone, lying between 400 and 500 feet beneath the Pittsburg coal bed, yielded most of the Dunkard's Creek petroleum. Of course the well diggers were bound to find their 'third sand,' and, in searching for it, struck the Freeport sandstone of the Allegheny River coal series (there about 600 feet beneath the Pittsburg coal bed), then the Clarion sandstone, and then the conglomerate. All these they called one sandstone; said it was 400 feet thick; and abandoned it because it yielded very little oil, or none at all. It is needless to say that, when they were at the bottom of their so-called third sand on Dunkard's Creek, they had not got within several hundreds feet of the top of the real first oil sand of the oil regions.

"THE OIL SAND GROUP.—Mr. Carll was the first to make known that the first, second, and third oil sands of Venango County form a single group, wonderfully regular in its total thickness of about 350 feet, and so persistent as a group as to be everywhere recognizable. The importance of this scientific discovery, in its practical applications to the wealth of the Pittsburg region, can hardly be overestimated; and one may well be surprised at the amount of facts to be collected, and the patience and skill in combining those facts to be exercised, before so simple a proposition of was discovered to be true.

"The first oil sand was struck in the Pittsburg (Boyd's Hill) well at 1,435 feet beneath low-water river level, as a white pebbly sand deposit, 112 feet thick, with slight show of oil, but flowing 4,000 barrels of salt water per day. More than fifteen years ago it was struck at Leechburg, on the Kishkaminitas; and a great rush of gas escaped from it, which was afterwards utilized in the iron-works. Recently it has become the great gas rock of the Murraysville district east of Pittsburg. It is now known to lie under Washington County, at the depth of 1,800 feet beneath the Pittsburg coal bed. It is there called the Gantz rock.

"The second oil sand in the new Washington district is called the Fifty Foot, and the third oil sand is called the Gordon rock.

"From the top of the Gantz down to the top of the Gordon is about 260 feet. In Venango County the interval from the top of the first down to the top of the third oil sand varies between 260 feet and 290 feet.

"Beneath the third oil sand at Pittsburg no oil is known to exist; but in the northern region of Warren County, and in Forest County, pools of oil have been struck at several points in the sandy beds of the great Chemung formation, which lies next underneath. These are the Warren oil sands. Far beneath them again, that is, say 1,000 feet beneath the oil-sand group, lie the phenomenal Bradford oil rocks, extending into the State of New York. What other members of the Devonian formations are repositories of oil, is not known; but we have every reason to believe that, if any exist, they are notably local, and therefore hard to find; and that, when found, they will make but a slight impression on the future oil production."

Among those lower Devonian formations are considerable thicknesses of black shale, no doubt darkened by petroleum; and in the Western States bitumen fries from their outcrops under the sun. Still lower down are great limestone formations, such as the upper and lower Helderberg and Niagara limestones, full of fossils, both vegetable and animal, and showing petroleum at their outcrops in a way to make it perfectly clear that it is the product of decomposition of organic matter.

*J. P. Lesley, State Geologist of Pennsylvania.

* The profile section (Diag. 11) follows a line drawn on the map drawn from Black Rock, on the Niagara River, Erie County, N. Y., to Pittsburg, and thence to the Dunkard Creek oil field in Dunkard Township, Green County, Pa., close to the West Virginia State line. From Black Rock to Pittsburg the bearing of this line is S. 20° W.— distance about 175 miles. From Pittsburg to Dunkard's Creek its bearing is S. 3° E.— distance 50 miles. The section from Brownsville to Dunkard's Creek is omitted, there not being room on the page.

Starting at Black Rock, the line crosses the foot of Lake Erie, and strikes the southeasterly shore at Lake View, in Erie County, N. Y. Thence it runs through or very near to the following places: Jamestown, N. Y.; Youngsville, on Broken Straw Creek, in Warren County, Pa.; Tidioute, on the Allegheny River, in Warren County; President, on the Allegheny River, in Venango County; Foxburgh, on the Allegheny, in Clarion County; Parker's Landing, on the Allegheny, in Armstrong County; and Petrolia, Millerstown, and Great Belt City (or Summit), in Butler County.

It is evident that as this allignment of the profile section coincides geographically so nearly with the trend of the Butler and Venango oil sands, there can be no trouble in properly locating upon it the Venango oil-sand group.

The Warren oil development, however, lies 8 miles to the east-southeast of our line, and the Bradford development 30 miles from it, in the same direction.

The lowest horizon in our country in which oil in paying quantities has been obtained is that of the corniferous limestone formation, the home of the Canadian oil.

This rock can be unmistakably identified at Black Rock, in New York; and therefore Black Rock has been selected as the northern end of our profile section (Diag. 11). The next, and only other point at which the elevation of the corniferous limestone can be fixed, is in the Coburn gas well, at Fredonia, Chautauqua County, N. Y.; for in Pennsylvania it has never been reached by the deepest borings.

The average pitch of the corniferous limestone towards the southwest can be calculated from its elevation at Black Rock and at Fredonia, allowing us to judge approximately of the thickness of the measures between it and the Venango oil group. At Black Rock, as shown by the quotations below, the exact thickness of the rock is not known. We have assumed the top to lie about 2 feet above the top of Lake Erie, or 625 feet above the ocean level, which cannot be far wrong. In the Coburn well at Fredonia, it is said to have been struck at a depth of 1,050 feet, which (the elevation of the well mouth being 735 feet) puts it 315 feet below the ocean level at that place. The distance from Black Rock to Fredonia is about 38 miles in a direction W. S. 35°W., and this gives an average slope or dip of about 25 feet per mile.

But along our section line S. 20° W. the average dip of the limestone ought to be stronger than 25 feet per mile, because the line runs more nearly in the direction of the line of greatest dip as calculated from other strata which admit of more accurate tracing; and this inference is strengthened by the fact that no limestone is reported at Jonathan Watson's deep well near Titusville.

The distance from Black Rock to Watson's well is about 100 miles; direction, S. 26° W.; elevation of well mouth, 1,290 feet above the ocean; depth of well, 3,553 feet. On an average slope of 25 feet to the mile the limestone should have been found at 1,875 feet below the ocean leve , or 3,165 feet from the surface. But, as no limestone is seen in the well, we must conclude either that it is absent in that locality (which is hardly probable), or that it has a greater average dip slope than 25 feet per mile in that direction. As the well stopped at 2,263 feet below the ocean level, an average of 29 feet per mile would put the limestone at 2,275 feet, or 12 feet beneath the well. A hard rock was reported, however, just as the utmost limit of drilling cable forced a suspension of the work, at a depth of 3,553 feet from the surface. A number of other deep wells are shown on the profile, but it will be seen that none of them have gone deep enough to reach the corniferous limestone. The Watson well is not only the deepest boring ever made in Western Pennsylvania, but it is also deeper geologically than any other. It is deeply to be regretted, therefore, that so little is known of its history.

* U. S. Census Report, 1885.

DIAGRAM NO. 10.

OIL AND GAS HORIZONS OF NEW YORK, PENNSYLVANIA, AND CANADA.

GENERALIZED VERTICAL SECTION FROM THE UPPER COAL MEASURES DOWN TO THE CORNIFEROUS LIMESTONE.

Compiled by J. F. CARL, for the Second Geological Survey of Pennsylvania.*
Drawn by LAURA LINTON.

COMPOSITION OF GROUPS.

Group 1. *Upper Barren Coal Measures (B)*, Greene Co. group. Vertical range, surface of the ground to Washington upper limestone, 600 ft. Composition: shale, limestone, sandstone, and coal. Exposure: the highlands of central and southwestern Greene Co., Pa.

Upper Barren Coal Measures (A), Washington Co. group, 350 ft. Vertical range, Washington upper limestone to Waynesburg sandstone. Composition: shale, sandstone, limestone; also Washington coal bed, from 7 to 10 ft. thick; limestone 1-3 of the mass. Exposure: highlands of Washington and Greene counties, Pa.

Group 2. *Upper Productive Coal Measures;* thickness, 475 ft. Vertical range, Waynesburg sandstone to base of Pittsburg coal. Composition: shale and sandstone; also limestone and thick beds of coal, of which the Waynesburg and Pittsburg are the most important. Exposures: Washington, Greene, and Allegheny counties, Pa.

Group 3. *Lower Barren Coal Measures;* thickness, 500 ft. Vertical range, base of Pittsburg coal to Mahoning sandstone. Composition: shale and sandstone, limestone and coal. Exposure: seen in Washington and Allegheny counties; also in the highlands of Butler and Beaver counties.

Group 4. *Lower Productive Coal Measures;* thickness, 400 ft. Vertical range, Mahoning sandstone to top of conglomerate. Composition: sandstone and shale, and coal seams; also limestone. Exposure in Butler, Armstrong, Clarion, Beaver, and Lawrence counties, Pa. The limestone of this group is from 5 to 25 ft. thick.

Group 5. *Mountain Sand Series, and Pottsville Conglomerate.* Vertical range, Homewood sandstone to Olean, O., conglomerate. Composition: variable conglomerates and sandstone; also the important coal beds, the Mercer and Sharon. Thickness, 375 ft. Exposure: Mercer, Crawford, Venango, and Forest counties, Pa.

Group 6. *Crawford Shale;* thickness, 400 to 500 ft. Vertical range, base of the mountain sands to Venango group. Composition shale and slate, inclosing the Pithole grit. Exposure: favorably seen in counties of group 5. Furnishes the amber oil at Smith's Ferry, O.

Group 7. *Venango Oil Group;* thickness, 300 to 375 ft. Vertical range, from the first oil sand to base of third. Composition: group of variable sandstone, slate, and shale. Exposure: in Butler County to Tidioute in Warren County.

Group 8. Between the Venango and Warren Oil Group. (300 ft.) Vertical range, Venango third oil sand to the top of Warren group. Composition: soft shale with beds of green, purple, and red sandstone.

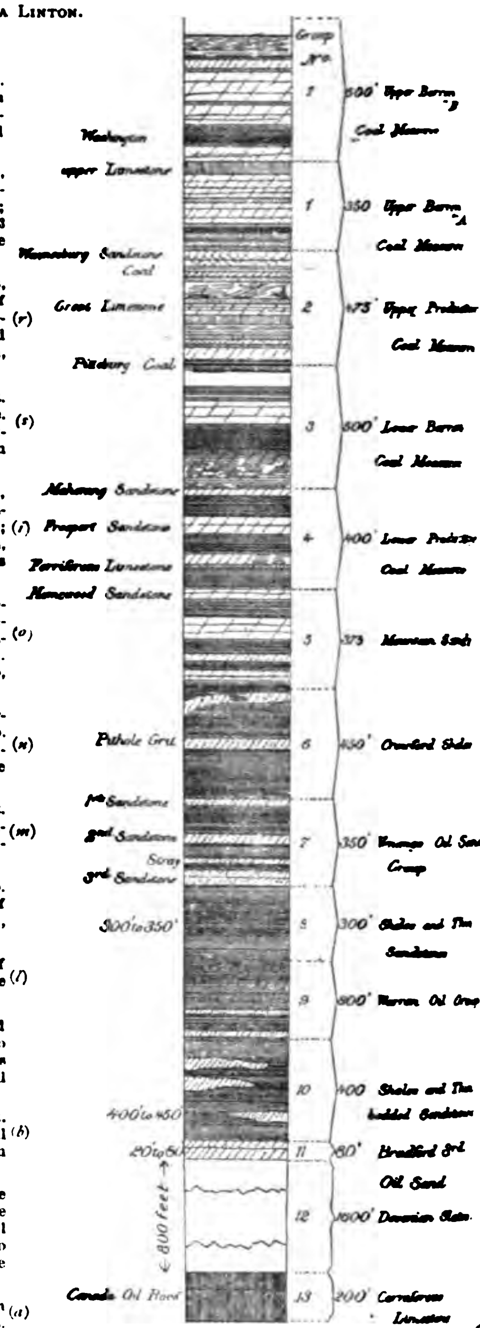
Group 9. Includes the so-called 2d, 3d, and 4th sands of Warren. Vertical range, from top of Warren shale to base Stoneham sandstone, covering, as nearly as may be, 300 ft.

Group 10. Between Warren oil group and Bradford third oil sand. Vertical range, from Stoneham oil sand to Bradford oil sand (400 ft). Composition: slate and shale. This is very fossiliferous. This interval holds the Bradford second oil sand.

Group 11. *Bradford Third Sand;* thickness, 20 to 80 ft. Composition: a fine-grained sandstone, containing small pebbles. Location, in the Wilcox wells, at Tidioute, and in Warren County.

Group 12. Between the Bradford third sand and the corniferous limestone; thickness, 1,600 ft. In composition the records are imperfect. No important bands of sandstone and no oil have been reported. The distance from Fredonia to Bradford is 48 miles. A dip of 20 ft. to the mile would place the limestone at Bradford as shown in our section.

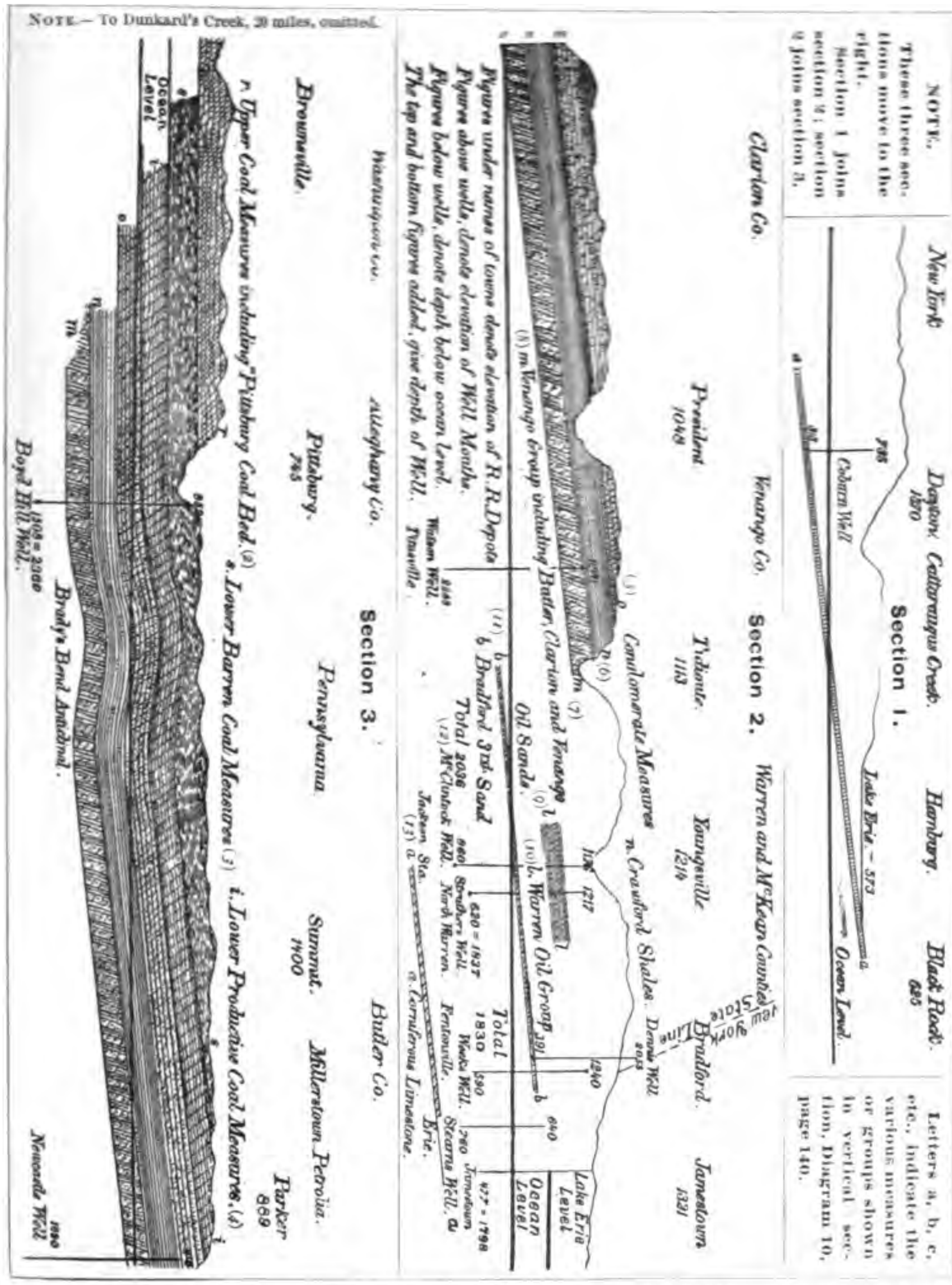
Group 13. This is the oil-producing rock of the Canada oil regions, but at Fredonia, N. Y., yields neither oil nor gas.



* U. S. Census Report, 1885.

PROFILE SECTION OF OIL REGIONS, BLACK ROCK, N. Y., TO WEST VA.

DIAGRAM 11. [Compiled by JOHN F. CARLL. Drawn by LAURA LINTON.]*

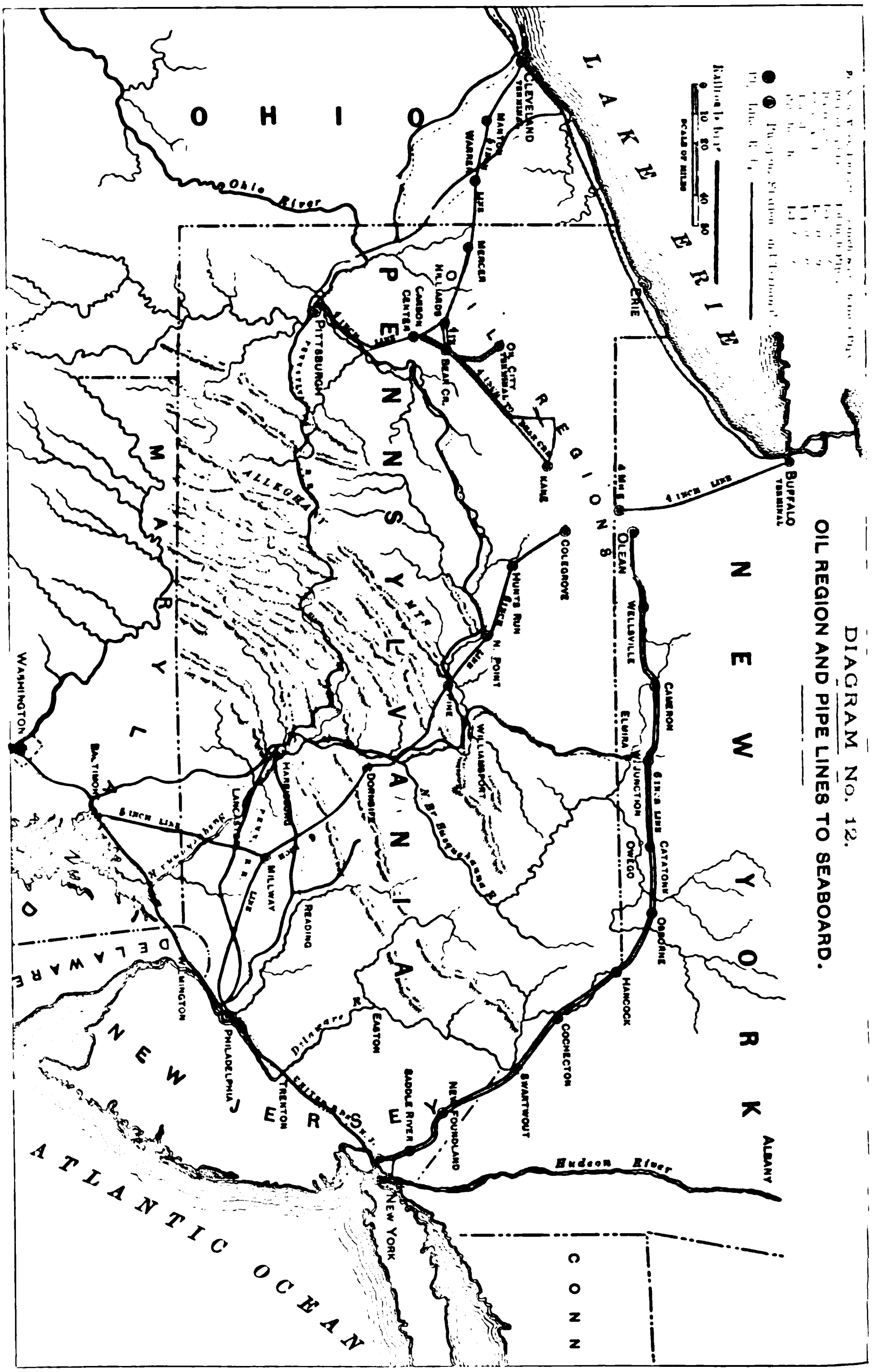


For full explanation of the composition of the several groups, see pages 139, 140, general vertical section; also map on page 142. The geology of petroleum and gas regions (page 138) is considered.

Reports of J. P. Lesley, State Geologist, permanency of oil and gas, page 177.

Distance from Black Rock to Pittsburg, 175 miles; Pittsburg to Dunkard's Creek, Green County, Pa., 50 miles. Scale, vertical, about 2,000 feet = 1 inch.

* U. S. Census Report, 1885.



For full description of these lines see pages 134, 135.

CHAPTER XI.

PETROLEUM OIL AS FUEL VS. COAL.

DURING the last ten years a great deal of attention has been paid to the subject of the utilization of petroleum as fuel, resulting in many experiments which have been reduced to practice, the experiments demonstrating its entire practicability and its immense advantages over any form of solid fuel. The question of its employment in this country, in competition with our abundant coal supply, is yet engaging the minds of some inventors. From the experiments which have been made, the following results can be relied upon: —

1st. That the calorific power of petroleum, for the purposes of generating steam and evaporating water, is several times greater than ordinary coal.

2d. That, where the price of petroleum does not greatly exceed that of coal, the former will be selected for all ordinary purposes of fuel, both for steam and furnace operations, especially when a high degree of heat is essential.

Since the first attempts to utilize petroleum, the prices of the two fuels experimented upon have relatively changed; coal has advanced, petroleum declined. Besides, with sounder views respecting the true theory of combustion, inventors have still further bridged the difficulties; and the very low prices of the liquid fuel invite renewed attention to the employment of petroleum as a substitute for coal, particularly under locomotive, marine, and stationary boilers.

Coal is very wastefully burned in actual practice, and the heat is imperfectly utilized, especially in locomotives; and only one invention out of the entire number that have attempted the solution of the question has actually succeeded in burning petroleum in the fire-box of a locomotive in such a way as to compare with coal in heat production.

The following considerations will, I think, make this point clear: — *

* C. E. Ashcroft, M. E.

One pound of carbon burned to carbonic acid will generate 14,544 heat units; while 1 pound of hydrogen, when completely burned, will generate 62,030 heat units. With this data, and knowing how much carbon and hydrogen 100 pounds of coal or oil fuel contain, it becomes an easy matter to calculate the theoretical heat-producing power contained in these two fuels.

The value of these 3 kinds of fuel is based on the percentage of bituminous coal containing carbon, 85; hydrogen, 5; ash and moisture, 10; total, 100. Anthracite coal containing carbon, 93; ash, etc., 7; total, 100. Petroleum oil fuel containing carbon, 86; and hydrogen, 14; total, 100.

From these data it is easy to compute the theoretical heat-producing power of the 3 substances, and we find that they are about as follows: One pound of bituminous coal will produce (theoretically) 15,465 heat units; 1 pound anthracite coal will produce (theoretically) 13,525 heat units; 1 pound of petroleum oil will produce (theoretically) 21,192 heat units.

The value of coal and petroleum varies in different localities, and the whole question of the utilization of either fuel hinges on the cost in dollars and cents of either coal or petroleum in the locality where it is desired to introduce it as a substitute for coal; and an illustration of this point is found in considering the values at present in this (Boston) market.

If coal be assumed to cost to large consumers $4.50 to $4.75 per ton of 2,000 pounds, and petroleum 2¾ cents per gallon, the oil weighing 7½ pounds per gallon, the relative value of the fuel is reduced to the question of how many heat units, as represented by the different fuels, will $1 purchase?

At the above valuation it is found that one dollar's worth of anthracite coal is represented by 444 pounds, and one dollar's worth of bituminous coal is represented by 421 pounds, and one dollar's worth of petroleum is represented by 270 pounds.

These various weights of the 3 different kinds of fuel, or a dollar's worth of each at the market value as above quoted, in heat-producing power are as follows: The 444 pounds of anthracite coal furnishes 6,005,544 heat units; the 421 pounds bituminous coal furnishes 6,510,765 heat units; the 270 pounds of petroleum oil furnishes 5,712,840 heat units.

In accordance with these deductions, the theoretical heat-producing power of a dollar's worth of coal and petroleum at the present prices is nearly equal in this market.

The theoretical heat of any fuel is easily determined, its proximate or elementary analysis being known; but the actual available heat is not so easily arrived at, and can only be determined by a series of more or less elaborate experiments or trials in actual use.

In steam boilers the efficiency of the furnace is measured by the pounds of water evaporated per pound of coal or other fuel burned under known conditions.

This will always be found to be below the theoretical quantity, and may be accounted for in many ways, as stated above.

The quantity of water evaporated from and at 212° Fahr. per pound of coal varied in practice from six to ten pounds.

With inferior coal the results would be below this. The quality of the coal must be taken into account, as well as the construction of the furnace. To obtain the highest results, the furnace should have the details arranged with special reference to the burning of a particular kind of fuel, as may be found, after a trial, the best and most economical arrangement for that fuel. This is especially true of any attempt to burn petroleum.

In a further consideration of the practical value of coal as fuel, it may be stated that 8 pounds of water evaporation is about the result obtained from the combustion of each pound of coal of the average quality under the ordinary conditions of its use. This gives about 57 per cent of the theoretical value, and this value is confined to the ordinary boiler of the stationary type.

The steam-producing power of petroleum (1 pound consisting of 6 parts of carbon and 1 of hydrogen) has for its theoretical evaporating power 22.08 pounds of water from and at 212° Fahr.

The accounts of the practical value of petroleum under the same conditions, as found in practice with coal, are not abundant; but there are records of its use which show that 16 to 18 pounds of water are evaporated from and at 212° Fahr., which gives (taking 17 as an average evaporation) an efficiency of 77 per cent of the theoretical value.

Therefore the efficiency of petroleum is found to be practically 77 per cent, as against an efficiency of 57 per cent in the use of coal when used in connection with the ordinary form of stationary boiler.

Having considered the efficiency of coal and petroleum as found in practice, in connection with the ordinary form of stationary boiler, and compared it with the theoretical value of these fuels, we pursue our investigations still further, and compare the value of these fuels, as found in locomotive practice.

The question whether coal will advance in price in the future and petroleum diminish, is not discussed any further than to say that the price of coal during the year last past (1887) has been considerably higher than has been known heretofore, and that, for several reasons, the price of this commodity will not diminish to any great extent; while, on the other hand, the price of petroleum, especially that product useful for fuel purposes only, has diminished during the past year (1887) to such an extent as to permit of its use in competition to coal. The recent action of the Standard Oil Company in laying a pipe line from the oil fields of Ohio to the city of Chicago, Ill., for the express purpose of furnishing oil as a fuel to that city, in place of coal, is significant to say the least, and the prospects are that a supply will be forthcoming at a figure that will permit of its use as a fuel in place of coal.

While the subject of the theoretical value of either coal or petroleum oil is by no means exhausted, sufficient has been said to show that the theoretical and the practical are widely separated, in so much that the full benefits of either oil or petroleum as a fuel are not obtained in practice, and, that so far as the latter is concerned, there has been little to show what was possible to obtain by its use, — in practice except in a few instances, — and the question presents itself, What are the reasons for the non-attainment of the full value of coal in practice? And answering this interrogation, the following may be stated as some of them.

1st. Difference in the chemical constituents of coal.

2d. Losses by conduction and radiation in the furnaces, flues, and metal of the boiler.

3d. Imperfect and incomplete combustion.

4th. Loss of heat carried off by the chimney, partly utilized in causing the draught.

5th. Improper management.

In addition to the above reasons there are additional causes for the loss of the theoretical value of coal in evaporative power, such as: —

The abstraction of heat from the combustible portion of the fuel, to bring the earthy matter and ash to the high furnace temperature; the unavoidable loss of some unconsumed coal during the abstraction of the clinkers; the direct loss of heat when the clinkers and ashes are withdrawn at the high temperature of the furnace; the influx of cold air through the open furnace door during the operation of feeding and cleaning fires; The loss of heat expended in raising the temperature of the air over and above the quantity needed for combustion; the loss of effect during the time that fires newly cleaned require to recover full action.

Comparing petroleum and anthracite coal in locomotive practice, the former has a theoretical evaporative power of 16.2 pounds of water per pound of fuel, and the latter of 12.2 pounds at an effective pressure of 120 pounds to the square inch; hence petroleum has, weight for weight, 33 per cent higher evaporative value than anthracite. Now in locomotive practice, a mean evaporation of from 7 to 7½ pounds of water per pound of anthracite is about what is generally obtained, thus giving 60 per cent of efficiency, while 40 per cent is unavoidably lost.

With petroleum, an evaporation of 12.25 to 14 pounds of water per pound is practically obtained, giving, say the lowest figures, 12.25, divided by 16.2, equals 75 per cent of efficiency.

Thus, in the first place, petroleum is 33 per cent superior to anthracite in evaporative power; and, secondly, its useful effect is 15 per cent greater, being 75 per cent instead of 60 per cent; while, thirdly, weight for weight, the practical evaporative power of petroleum must be reckoned as at least 12.25 minus 7.50, equaling 63 per cent, to 12.25 minus 7.00, divided by 7.00, or 75 per cent higher than that of anthracite.

Returning to our original position, it is demonstrated that where $1 will purchase the same, or nearly the same, number of heat units, petroleum fuel is superior, and possesses advantages over any form of solid fuel, and the use of this petroleum fuel is destined to become more generally introduced as soon as the superiority becomes known.

* FUEL OIL APPLIED TO LOCOMOTIVES.

Experiments have been made by different inventors during the last fifteen years, more or less, having for their object to devise a successful method of burning oil.

Without attempting to give an accurate or connected history of these earlier experiments, it is perhaps sufficient to say that most of them, or until the last two or three years, attempted to convert the oil into a gas or vapor before trying to burn it. The general result of all these experiments is that the preliminary treatment did not prove successful. Now we know that previous preparation is entirely unnecessary, and that petroleum can be burned with perfect success and with almost complete combustion of the oil without any preliminary preparation or treatment.

It is perhaps difficult to say who first struck the essential feature of practical petroleum burning, but it is fairly safe to affirm that Mr. Thomas Urquhart, of Borisoglebsk, Russia, Locomotive Superintendent of the Grazi-Tsaritzin Railway, made the first successful attempt on a large scale to use petroleum as fuel.

*Dr. Charles B. Dudley, *Journal of the Franklin Institute*, August, 1888.

It is perhaps safe to say, in view of what has actually been done, that oil burning, so far as it depends on a method of doing the burning, is a success, and that this part of the problem is solved. The problem that remains is: Can oil be burned as a means of generating heat with economy?

The following table shows the relative heat-producing power of coal and oil. In the theoretical part of this table the following assumptions are made: A pound of anthracite coal is supposed to contain 90 per cent of carbon. A pound of bituminous coal contains 85 per cent of carbon and 5 per cent of hydrogen. A pound of oil contains 86 per cent carbon and 14 per cent of hydrogen.

RELATIVE HEAT-PRODUCING POWER OF COAL AND OIL.

	Lbs. Oil.	Lbs. Coal.
Theoretical anthracite	1	1.61
Theoretical bituminous	1	1.37
Urquhart's experiments	1	1.756
Peninsular Car Company's experiments	1	1.742
Elevated Railroad, New York	1	1.785

It will be observed that Mr. Urquhart's experiments, which we may say are the result of a year's experience with the same one hundred and forty locomotives burning coal and using oil, show that a pound of oil will generate as much heat as one and three-fourths pounds of coal.

The experiments of the Peninsular Car Company, at Detroit, Mich., were made with the Canadian petroleum, in October, 1885, and show, as is observed, a very close agreement with Mr. Urquhart's figures. The experiments by the Elevated Railroad in New York were made during the summer of 1887.

The ratio of coal and oil being determined, we are at liberty to begin the consideration of the financial part of the problem. Assuming that a barrel of oil contains 42 gallons, and that a gallon weighs 7.3 pounds, we compute the following table, in which the first column under the heading coal considers the fuel account alone, and *the second column under the same heading considers all ascertained economies:*—

Oil per Barrel.	Coal per Ton.	Coal per Ton.
$0.20	$0.74	$0.65
.30	1.12	.98
.40	1.49	1.30
.50	1.86	1.63
.60	2.24	1.96
.70	2.61	2.28
.80	2.98	2.61
.90	3.35	2.93
1.00	3.73	3.26
1.10	4.10	3.59
$1.20	$4.47	$3.91
1.30	4.85	4.24
1.40	5.22	4.56
1.50	5.59	4.89
1.60	5.97	5.22
1.70	6.34	5.54
1.80	6.71	5.87
1.90	7.08	6.19
2.00	7.45	6.52

Mr. Urquhart is a Scotchman by birth, and has been now some nineteen years in Russia; and when I visited him in October, 1886, he had one hundred and forty-three locomotives in daily use burning nothing but petroleum, as well as a large number of stationary boilers, pumping engines, machine shop engines, etc. Indeed, the whole Grazi-Tsaritzen Railway uses almost nothing but petroleum for heat generation. The essential features of Mr. Urquhart's system may be perhaps briefly described as follows: —

1st. The burner, which converts the oil into a spray, or very finely divided condition.

2d. The location of the burner in such a position as regards the fire that it never becomes hot and consequently never clogs.

3d. The location within the fire box of a mass of fire brick, so arranged as to form a combustion chamber, and to serve as a radiating point for the heat, and also, to a certain extent, for the storage of heat. The fire-brick arrangement has the still further advantage of breaking up any particles of oil that escape from the burner unpulverized, so to speak, and also of igniting the oil after it has been shut off at any time.

There are two other methods of burning petroleum, one of which, at least, is in general use in Southeastern Russia; namely, the Lentz system. This system is used extensively on the Volga steamers. It depends for its success apparently on the same principles that have been already described; namely, it converts the oil into a finely divided state by means of steam, and burns this mixture of spray and steam. We believe there is no brickwork required, the material being injected into the fire box.

In this country the Edwards and other oil burners have been used with considerable success; these likewise convert the oil into a spray; doing it in a little different way, however, than the method by Mr. Urquhart. We have seen likewise two pieces of tubes used one inside the other, and with the control of the steam and the oil by means of globe valves, the mixed steam and oil being projected into an ordinary fire box. This is used on stationary boilers in the oil region.

In the winter and spring of 1886–87 experiments with the Urquhart system of burning petroleum were tried on the Pennsylvania Railroad.

The firing on oil-burning locomotives is simply ideal. Only those who are accustomed to it can detect the least little smoke on the presence of the steam as it leaves the smoke stack. The comfort of the passengers by the use of this magnificent combustible for generating steam can hardly be described. Not a cinder or trace of smoke ever disturbs them. Windows can be left wide open as far as the locomotive is concerned.

Advantages which oil has over coal as a fuel: 1st. Less waste of fuel. 2d. Economy in handling. 3d. Economy in handling ashes. 4th. Diminished repairs. 5th. Economy in cleaning engines. 6th. Less waste of steam at the safety valve. 7th. Economy of space in carrying and stowing fuel. 8th. No fires from sparks. 9th. No smoke and cinders. 10th. Possibility of utilizing more of the heat.

*USE OF DEAD OILS AND WASTE FOR FUEL.

By the courtesy of Messrs. Havill & Company, of the Gresham Building, E. C., the agents in chief of Tarbutt's Liquid Fuel Company, Limited, we were enabled to witness, says *Wigan Observer*, the application of the patent apparatus, the invention of Mr. Percy Tarbutt, to the generation of steam by the use of liquid fuel in the form of petroleum residuum, or the dead oils produced by the distillation of coal and shale. The boiler was an externally fired tubular one of thirty horse-power, nominal, and had a furnace with a fire-brick lining, similar to those of Siemens regenerators. At the end of this furnace, or rather combustion chamber, was a fire-brick baffle, having apertures through which the heat passed to the tubes of the boiler.

In this chamber is a coil of iron pipe, one end of which is connected with the steam space in the boiler; and the other opens out into the door of the furnace, in conjunction with the petroleum or oil nozzle. This coil is for the purpose of superheating steam taken from the boiler, and by it an induced current is set up, which carries the liquid fuel forward into the combustion chamber. In order to enable it to do this, the oil nozzle is placed within the steam pipe at the opening where it delivers its jet, so that an annular space is formed, through which the steam rushes, combines with the oil drawn through the interior nozzle, and produces a large volume of intense and almost colorless flame within the combustion chamber.

It was observed that the flame did not directly impinge on the superheating coil, which was inclosed in the combustion chamber, and so obviated the danger of the iron coil being burned away by the intensity of the flame, a defect apparent in some other inventions for a similar purpose. The oil is stored in tanks above the level of the furnace, so as to flow to the delivery nozzles by gravity. The whole apparatus is very simple and easily adjustable, and so arranged that fire bars for using coal or solid fuel can be easily substituted in case of any failure in the supply of the liquid. The system has had a thorough trial on board the "Himalaya," a steamship of eight hundred tons and one hundred horse-power nominal, which has been running between London and Glasgow with very satisfactory results.

Modern Light and Heat.

This ship is now supplied with liquid fuel from the works of its owners on the coast of Brazil, where she is now employed for trading purposes. The principal advantages connected with the employment of this system are perfect combustion, there being no deposit of carbon in the tubes or flues of the boilers, and no smoke issuing from the chimney; it is labor saving, ordinary stoking being done away with, as the whole supply is regulated by the adjustment of the taps and valves, and the storage would not be half as much as now required in steamships, thus allowing more space for cargo.

The question of economy will, no doubt, to a great extent, be affected by the relative values of solid and liquid fuel at the place where the system may be adopted; but it may be stated that the effective value per ton is about three times that of the best steam shale, which was employed in the oil manufacture, and from it twenty-five million gallons of paraffine were produced. In 1884 the output was increased to two million and ninety thousand tons. From this crude oil is manufactured paraffine wax candles, burning oil, machinery oil, and two valuable manures; and the dead oil that remains after producing these is the material used for fuel in competition with crude petroleum, and is, indeed, preferred by the users of the Tarbutt apparatus.

***Manufacture of Iron.** A large number of processes have been invented and patented for using raw petroleum in the manufacture of iron. Of these the Eames process seems to have been the most successful, and to have had the most satisfactory trial.

The Eames process has been put into practical operation both at Titusville, Pa., and in Jersey City, opposite New York. Why it has not proved a commercial success, I have not been able to learn. Competent judges, having an interest in the success of the establishment at Titusville, bear witness to the extraordinary fine quality of the iron produced from scrap and refuse of the most forbidding character.

I quote the language of Professor Wurtz's memoir respecting the working of the apparatus described:—

"It is quite easy to determine with precision, with the arrangements in Jersey City, the relations of consumption of oil to iron produced, and the time, labor, and material in any particular case. The oil was fed from a tank sunk in the ground, which has a horizontal section throughout of 4 feet square. Each inch in depth, therefore, corresponded to 2,304 cubic inches, or, closely enough, to 10 United States gallons of 231 cubic inches. By gauging with a graduated rod each hour, therefo[illegible]rly [illegible]ion of oil was readily followed up.

* [illegible]ensus Reports.

It was thus determined by me that, starting with a cold furnace and boiler full of cold water, 45 minutes was a maximum time, with oil fed at the rate of 30 gallons per hour, or 22.5 gallons in that time, to bring the whole fire space to a dazzling white heat. Six piles of boiler scrap, averaging 600 pounds, or 3,000 pounds in all, being then introduced, 35 minutes more of the same rate of consumption not only brought the piles to a high welding heat, but raised steam in the boiler to 90 pounds pressure, being that required to operate the rolls. The time required, after the furnace was heated and steam up for each charge of 3,000 pounds, averaged at most 80 minutes; and, as the brickwork became heated throughout, it was apparent that the feed of oil might be somewhat diminished. Thus, in a working day of 10 hours, just 7 such charges could be worked off, averaging 2,500 pounds of rolled iron each; total, 8 tons per day of boiler sheet from one such furnace, with an average consumption, as a maximum, of 30 gallons (200 pounds) of oil per hour, or 300 gallons (2,000 pounds) in all. To this must be added, however, the fuel used under the generator and small supplementary boiler, which together was 500 pounds per day.

"It is admissible that one generator and one small boiler will operate several furnaces; the inventor says five. If we say four, it will diminish the small addendum of cost.

"As to working this furnace with coal, it was ascertained from the testimony of the operators that, by keeping up the fire all night, so that a heat could be had at a reasonable time in the morning, the maximum product of finished sheet might be, with superior work, allowing 90 minutes for each heat, 6 tons, with a consumption of at least 5½ tons of coal, equal to 12,320 pounds, or 2,053 pounds of coal per ton."

Oil as Fuel in Pennsylvania. Petroleum has always been burned for steam fuel more or less in the oil regions of Pennsylvania. All sorts of experiments have been made here to burn the crude oil, both pure and mixed with steam. Mr. D. A. Wray, on Oil Creek, filled with crude oil, at 50 cents a barrel, an eight-horse boiler, with safety valve attached. He fired up under it as if it had been filled with water, and burned the vapor as if it were gas. The arrangement worked well until the spaces between the boiler tubes became choked with coke. This deposit of coke from distillation of the oil has been found to be the chief practical difficulty, and has been usually avoided by injecting steam through the escaping oil in such a manner as to completely volatilize it.

Another practical difficulty observed by Mr. Wray was explained by him as in accord with an observation made by Tyndall, that the flame of a Bunsen lamp is intensely hot to objects immersed in it, but that it radiates comparatively little heat.

Mr. Wray has observed that all successful contrivances for burning petroleum must distribute the flame *upon* the surface to be heated, and not *beneath* it. Inattention to this condition is the cause of many unsuccessful attempts to generate steam by the use of crude petroleum.

It is impossible that I should attempt to describe the great number of apparatus devised for burning the crude oil, many of which are entirely adequate. The successful use of the oil for years in stationary engines has demonstrated the absence of all serious practical difficulties. The questions of economy and safety appear to have determined that for general use it is not a desirable fuel; while in special cases it has been attended with complete satisfaction.

The action of hydrocarbons at a red heat has been investigated by M. Coquillon. He shows that steam assists the decomposition of the hydrocarbons, producing at the same time a fall of temperature, which is added to that produced by the reduction of carbonic oxide and carbonic acid.

GASOLINE.

"We are often asked the questions by people who are not acquainted with the products of petroleum: 'What is gasoline? What is it made of?' The answer is: It is one of the light products of petroleum. Every hundred barrels of crude oil, as it is pumped out of the wells, contain about fifteen barrels of gasoline or naphtha. In the process of refining this oil, the gasoline is separated from the rest, and is redistilled and refined, and is then called refined naphtha, benzine, burning fluid, and gasoline, according to the gravity it bears. The best gravity for use of these stoves is seventy-four, and nothing heavier should be used, as it is likely to contain traces of oil and paraffine, which fill and clog up the burners.

"The common theory advanced is that gasoline is explosive, and consequently dangerous. It is, like so many other things, perfectly safe in safe hands, *but more or less dangerous in unsafe, ignorant, or careless hands*. People who use it should inform themselves of its character, so that they will know how to handle it safely, and know wherein its safety or danger lies; and the vapor escaping from a can with the screw top off, in an ordinary closet or living room, can do no harm. But when agitated in drawing or filling a can or reservoir, considerable vapor escapes, and this vapor is capable of taking fire a distance away from the vessel, and this is where the dangerous part comes in. It should never be handled near a fire or light, and, if necessity compel it, the light must be held up high above the liquid, as the vapor is heavier than air, and always descends. Never fill a stove when burning, nor fill it full to overflowing before lighting."

† **Stoves.** During the last few years stoves in a great variety have been contrived in which some of the products of petroleum have been consumed as fuel. Practically they may be divided into naphtha and kerosene stoves; a vast number of them are sold each year.

"The kerosene stoves are being brought to a great degree of perfection, and are found to be very useful. Of the several manufacturers who are seeking the patronage of the public, I am not disposed to select any as making in all respects an article superior to all others. These stoves act best with high test oil, and are therefore safe. *Their healthfulness depends on the manner in which they are used.* It is claimed that one of these stoves with two burners discharges an amount of carbonic acid into the atmosphere of a room equal to the respiration of two and one-half persons. I have not examined the merits of this statement; but, assuming it to be correct, it is a sufficient reason why the most thorough ventilation should be urged upon those having these stoves.

"Very few are used under circumstances that admit of the removing the products of combustion from the apartment; and, when one is placed in a small room occupied by two persons, the *contamination of the air amounts to that caused by the constant occupation of the room by four or five persons.* When to this unavoidable source of impure air is added the sulphurous acid and half-burned products of combustion of pure and cheap oil, petroleum stoves cannot be recommended as conducive to good health. Yet they are cheap and convenient, and thousands are sold annually.

"Petroleum and nearly all of its products are employed in glasshouses for producing high temperatures and flames free from soot and other materials which would injure the glass. At Wheeling, W. Va., one of the largest glasshouses uses benzine for producing the intense heat of the 'glory holes,' and other houses use natural gas for the same purpose."

*FURNACES FOR BURNING LIQUID FUEL.

The methods of burning liquid fuel may be classified under three heads, according to the use of the oil in a liquid, steaming, or vaporous condition, designating the classes as: —

1st. Hearth fires. 2d. Gas fires. 3d. Spray fires.

Hearth Fires. In this class are included all those methods in which the design is to place or pour the liquid directly into the fire box, with such an equal distribution as will secure complete combustion. This class may be again divided into: —

1st. Pan fires. 2d. Step fires. 3d. Drip fires. 4th. Oozing fires.

† S. F. Peckham in U. S. C. Reports. * *Power-Steam*, June, 1888.

Pan fires are the simplest and most primitive form of devices for burning liquid fuel; but the general trouble with them is that it is almost impossible to get a sufficient supply of air, and consequently the combustion is imperfect.

Biddle's method, which was specially intended for marine boilers, was tried about 1862, but never came into general use. There was a cast-iron fire box made in one piece, closed at the bottom, on which there were grooves radiating from the centre to secure distribution of the oil, which was supplied from a storage tank above the boiler.

Step fires are among the oldest devices in use, and are preferable to pan fires because air can be admitted from both sides, and because the mass of liquid fuel is much thinner than in pan fires, and better combustion can be attained. The most prominent systems of this class are those used by Nobel and Ostberg in Sweden. This system consists of a series of iron troughs arranged in the form of a series of steps. The oil enters the uppermost trough, and then overflows into the others until it is all burned.

Drip fires are perhaps superior to pan or step fires, the burning oil being distributed in separate grooves.

Nevertheless, the distribution and subdivision of the oil have never been carried far enough on this system to insure perfect combustion. A system invented by M. Andouin was exhibited at the Paris Exposition of 1867. In place of a door to the fire box a plate was attached, to which were affixed at the top and in the centre rows of small iron pipes, each of which had a tap and could be cut off from the supply pipe. To the mouths of the pipes a vertical groove was fitted, down which the ignited oil was conducted. The plate that took the place of the door had openings one-fifth inch wide between the grooves for the admission of the air.

Oozing fires are thought by some authorities to be the most successful of the *hearth* class of furnaces for liquid fuels, as by means of the layer of porous material employed an efficient distribution of the fuel is secured.

Perfect combustion cannot, however, be insured for long, as the oil does not burn equally, its lighter components being given off first, while the heavier constituents remain in the porous layer through which the liquid fuel oozes, and so choke up the layer that the lighter oils which feed the fire find great difficulty in oozing through.

The Patterson oozing furnace was tried in New Jersey about 1878, and was remarkable for the speed with which steam could be generated from cold water.

The device consisted of an iron tank filled with asbestos. There were openings in the side of the tank, and the oil was introduced from below through a pipe which was regulated by a tap. As soon as the asbestos became saturated with oil, it was lighted, and the flames rose up out of the asbestos and through the apertures at the sides of the tank. Although the combustion was not very perfect, an intense heat was developed, but the use of this system has never been extended.

Gas Fires. This class of furnaces embraces those in which the fuel is used in a gaseous state. The number of devices of this kind is comparatively small.

The Foote gas furnace was tried on the gunboat "Palos" by the United States Navy Department in 1867. This furnace consisted of a cast-iron retort with a riveted wrought-iron bottom, which could be fixed to any boiler grate by the removal of the fire bars. The petroleum was introduced into this retort by a pipe about one eighth of an inch in diameter. The vapor of the petroleum then streamed out of the burners through another set of pipes. To start the fires, it was necessary to kindle a wood fire on the floor of the retort until the heat became sufficient to volatilize the entering petroleum, and the heat was then maintained by the burning gas. This system was abandoned because of the constant repairs and the trouble of keeping it in working order.

Spray Fires. This class includes all the latter plans for burning liquid fuel. In these methods the oil is divided into small sprays by a steam and air jet, and is then nearly completely consumed in a vaporous condition by means of the air, which generally is introduced by the draft caused by the jet. The temperature attained by these fires is so high that it is found necessary to protect the sides of the fire boxes by fire-brick covering, or else to divert the direct flame from them. In considering spray fires, classification may be made upon the basis of the various forms of sprinklers used to divide the oil into fine sprays.

Slit sprinklers are the first to be considered. In that introduced by Lenz in 1870 on steamers on the Volga River and Caspian Sea, the sprinkler was of cast brass, and divided by a partition in halves, so as to prevent the intermixture of the oil and steam. The partition terminates in the front in a tapering tongue, in the grooves of which the oil flows out, to be blown away in thin sprays by the steam that issues from the under side of the tongue. It is objected to slit sprinklers, as a class, that they entail so much waste of oil that their use is possible only in oil regions, where the fuel costs little or nothing.

Pipe sprinklers have proved themselves more economical than slit sprinklers, and are more readily cleared when stopped up by residuum and impurities.

Results of some experiments at the repair shops of the Boston & Albany Railroad, Springfield, Mass. The following experiments were made by L. P. Breckenridge, M. E., Sept. 6, 7, 8, 9, and 10, 1887, to see with what efficiency oil could be burned with the apparatus and appliances controlled by the Aerated Fuel Company, of Springfield, Mass.

The two boilers with which the experiments were made were rated at eighty horse-power. They were of the locomotive type, well covered with wood lagging, over which was a Russia iron covering, so that the radiation was reduced as much as possible.

The two boilers were of the same dimensions, stood side by side in the same room, had a common steam pipe, and were fed by one injector. One of the two boilers is supplied with two oil reservoirs. The oil to be burned is forced through a small (three-sixteenths inch) pipe inside, while the *air* which serves to spray the oil passes along the larger (three-fourths inch) tube outside. The regulation is effected by changing the position of the inside tube.

In the tests under consideration the air was supplied to the side reservoirs by an *air pump*, the same as used to pump air for the Westinghouse air brakes, size of the air cylinder being eight inches in diameter, stroke eight inches. All the water fed to the boilers during these tests was carefully weighed in uniform amounts of four hundred pounds. All the oil was also weighed, the suction pipe from the oil pump being carried to a barrel placed on scales for this purpose.

The steam for running the air pump was taken from the boilers; and, in order that the amount of steam used to furnish the necessary air for spraying the oil might be known, the exhaust steam from the pump was all condensed, and the condensed water weighed.

Before making the test on the oil, several trials were made to determine the most economical pressure to carry on the air for spraying. This was found to be nearly *ten pounds per square inch.* Below seven pounds steam could not be kept up to the desired pressure, while above fourteen it was necessary to shut off one burner on each boiler occasionally; while the steam used by the air pumped increased without an increased evaporation in the boiler.

While burning coal, there was a damper regulator attached to the boiler, which held the steam constantly at one pressure. A similar arrangement for regulating the flow of oil through the burners by the steam pressure will be found useful and beneficial.

Table No. 5½ is a condensed summary of four runs with oil and one with coal, to which is added an analysis of the oil by Charles Mayer, of Springfield.

CONDENSED TABLE OF COAL AND OIL TESTS. NO. 5½.

***Experiments of L. P. Breckenridge, at Springfield, Mass., September, 1887.**

1.	Date of tests, 1887	Sept. 7.	Sept. 6.	Sept. 6.	Sept. 9.	Sept. 8.
2.	Kind of fuel	Oil.	Oil.	Oil.	Oil.	Coal.
3.	Duration of test	9 hrs.	2 hrs. 30 m.	5 hrs.	5 hrs. 10 m.	9 hrs.
4.	Consumption of oil, total in pounds	1676	455	930	1038	2250
5.	" " " per hour in pounds	186.22	182 0	186.0	201.0	250
6.	Average temperature of feed water	68.	68.5	68.0	65.5	67.
7.	Boiler pressure in pounds by gauge	63.86	64.67	62.44	64.50	66.90
8.	Total water evaporated, actual conditions, pounds	2182.9	599.0	1171.6	1302.6	2030.7
9.	" " " per hour, actual conditions, pounds	2425.6	2396.0	2343.2	2522.5	2256.3
10.	Water evaporated by 1 pound oil, " " "	13.02	13.16	12.60	12.55	9.03
11.	" " " " " at and from 212° F "	15.40	15.54	14.86	14.83	10.68
12.	Average air pressure on oil in pounds (by gauge)	9.35	9.34	{12.55 3 hrs. / 7.88 2 "}	13.6	——
13.	Steam used per hour by air pump, pounds	157.3	157.3	{189.6 3 hrs. / 142.2 2 "}	200.41	——
14.	Total steam used by " "	1415.7	393.2	853.38	1035.4	——
15.	Per cent of steam generated used by air pump	6.38 p. c.	6.56 p. c.	7.28 p. c.	8.00 p. c.	——
16.	Strokes of air pump, per minute (double)	36.5	36.5	44—3 hrs. 33—2 "	46.5	
17.	Temperature of escaping gases, No. 1 Boiler	332°	——	327° 3 hrs. 325° 2 "	310.5°	285.7°
18.	" " " " " 2 "	302°	——	301° 2 "	308°	269.1
19.	" " steam in boilers	310.7°	312°	309.7°	311.4°	313.5
20.	Water evaporated per square feet of heating surface, per hour	.97	.958	.937	1.01	9.02
21.	Consumption of oil " " " " grate " " "	8.86	8.86	8.86	9.60	11.9

COST AND EFFICIENCY OF EACH FUEL.

		COAL.	OIL.
1.	Pounds of water evaporated at and from 212° per pound of fuel	10.68	15.54
2.	Price paid for fuel per ton (2000 pounds) and per barrel	$4.50 ton.	$1.16 bbl.
3.	Number of pounds, costing $1.00	444.4 lbs.	236.3 lbs.
4.	British Thermal Units (B. T. U.) contained in each pound of fuel	14.800	18.450
5.	B. T. U. transferred to water in boiler per pound of fuel	10,317	15,012
6.	Per cent of heat in fuel transferred to water in boiler	69.7 p. c.	78.7 p. c.
7.	B. T. U. which can be bought for $1.00	6,577,120	4,359,735
8.	B. T. U., costing $1.00, which may be transferred to water in the boiler	4,580,748	3,542,332
9.	Price of same number of B. T. U. delivered to water in boiler by each fuel	$ .77	$1.00

ANALYSIS OF THE OIL.

The oil used was from Lima, O.; it was carefully analyzed by Chas. Mayr, of Springfield, and the following is copied from his report:—

"By ultimate organic analysis, the oil was found to consist of, hydrogen, 17.10 per cent; carbon, 80.20 per cent; oxygen impurities, 2.70 per cent.

"The specific gravity of the oil at 75° is .831. One cubic foot weighs 51 lbs., 14 oz. One gallon weighs nearly 6¼ lbs."

* Method and apparatus of the Aerated Fuel Co., described on page 157.

The Ashtabula Tool Company writing to the Aerated Fuel Company, of Springfield, Mass.: —

ASHTABULA, July 12, 1888.

MR. J. H. BULLARD, *Manager*, Springfield, Mass.

DEAR SIR: During the past two years our company have been endeavoring to find some economical fuel to take the place of anthracite coal in our general work of manufacturing agricultural implements.

Although not being in the "Natural Gas Belt," we have two gas wells upon our premises, which furnish a supply the season through for one furnace. We had investigated many devices for using crude oil, but found nothing that was practical in our business, where a quick and high heat is required in large and small furnaces and upon a wide variety of work, such as welding, tempering, brazing, and the general working of steel and iron. We wanted a fuel that would work as near like natural gas as possible, quickly started, and easily applied to our different kinds of work. Some three months since our attention was called to your system of aerated fuel. Upon investigating the process, we were convinced that it would meet our wants, and arranged at once to introduce it generally into our fires (twenty-seven furnaces). We have been running about two months with the aerated fuel, having used neither coal nor coke during this time.

We wish to say to the Aerated Fuel Company that this system has more than met our highest expectations. The fires are a complete success in every forge. They are clean, safe, and easily run. Our workmen like them better than the natural gas (the natural gas and oil fires working side by side). There is less scale, the metal is softer, and works easier. The oil fires start up and heat about as quickly as the gas, and run as steadily and uniformly the ten hours through the day. As to economy, our system is so arranged that we can tell exactly how much oil we are using. We are running these fires for less than one sixth what it cost us for coal. In forges where we used from two hundred and twenty-five to two hundred and fifty pounds Lehigh egg coal per day, we now run with seven gallons crude oil, and get a better and more even heat.

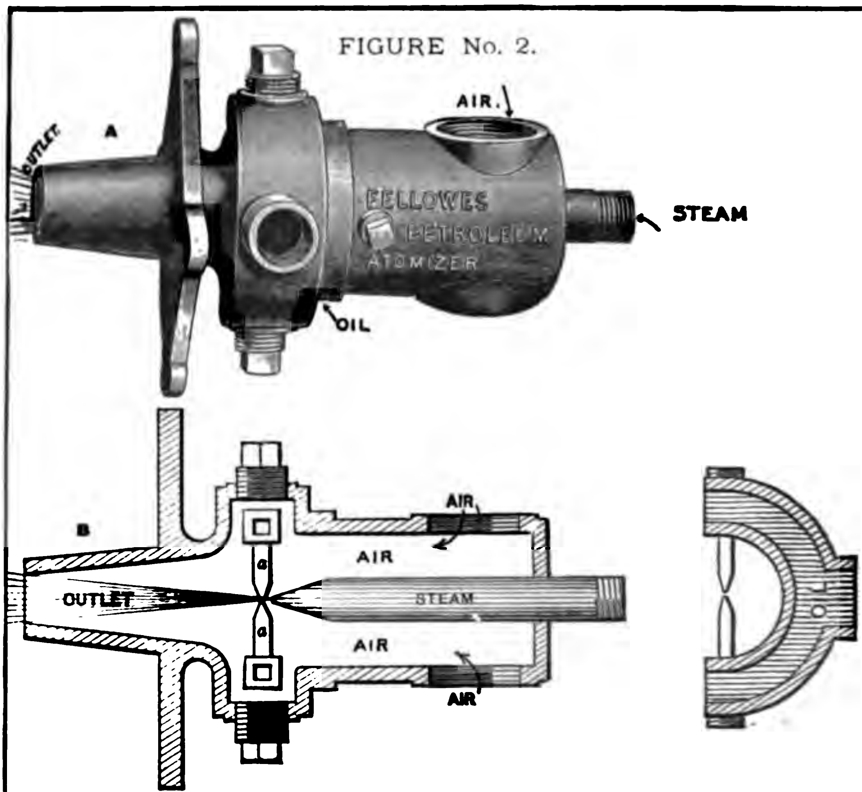
When some of the many advantages of using oil over coal are looked into,— such as the cost of handling the coal into the shop and cinders out, the quick heat after starting fires morning and noon compared with the waiting for coal,— we find a saving of over 85 per cent in favor of the oil. With your system there is no waste heat. In fact, no heat save just where it is wanted, the materials needed being concentrated there. We are aware we have made a strong statement, but the facts will bear out all we have written you in regard to this new system of economical fuel.

The use of petroleum for fuel for forges or furnaces, where the character of the product is improved or the product itself increased, is where it can compete much more successfully with coal. The Franklin Moore Company, Winstead, Conn., writes as follows concerning the subject: "We find that a barrel of crude oil will run a forge fire for seven days, that has used one hundred and twenty pounds of coal per day upon the average. But even if it cost more than coal, we should feel constrained to use it, because it is such an even fire all the while, needs no attention, makes no ashes, and gives us full value for every cent we pay for fuel.

"Cost of coal seven days, $2.73 [illegible]"

Without going into the relative cost of petroleum oil found elsewhere, which varies in every market, we submit the following statement of results said to have been obtained in dollars and cents, and leave our readers to calculate the evaporative efficiency in the same units on an evaporation of say ten pounds of water with one pound of coal, and the prices of the two classes of fuel which can be had in their own vicinity.

FIGURE No. 2.



*A NEW PETROLEUM BURNER.

At the Michigan Carbon Works, Detroit, Mich., there were burned:—

During November, 1887, 764 tons of lump coal, at $2.70 per ton	$2,062.80
Unloading at 8 cents per ton	61.12
Labor for firemen and wheeling	286.45
Total	$2,410.37

During November, 1888, there were burned:—

2,061 barrels of crude oil at 55 cents per barrel	$1,133.55
Labor for firemen	120.00
Total	$1,253.55
Amount saved over corresponding month last year or 48 *per cent.*	$1,156.82

Tests made with this burner have shown an evaporation of *sixteen and two-thirds pounds of water with one pound of oil.*

* Empire Hydrocarbon Co., 18 Exchange Place, New York, N. Y., from *Power Steam*, Jan

Brandt's pipe sprinkler was introduced in 1880, principally for marine engines. The oil and steam mix in the space between the needle and the cap, which is regulated by a screw in a brass casing, and enter the fire box in a conical bundle of streams, which are then consumed.

Smith's pipe sprinkler, recently patented in England, consists of two concentric pipes, of which the inner one can be displaced against the outer, and a central screw spindle with a cone-shaped outlet. The outer pipe receives the oil from the supply pipe, and the oil mixed with air enters the inner pipe through openings in its circumference, and reaches the cone outlet. The space between the inner and outer pipes is filled with steam, which streams out of the cone-shaped outlet in a circular form.

PETROLEUM BURNERS.

In the search for cheaper fuel many expectant glances have been cast in the direction of petroleum, and many endeavors made to utilize the heat so abundantly stored in this convenient form.

For some reason or other, notwithstanding the advantages which this fuel offers, no system of burning it seems yet to have met with very universal adoption, although considerable progress has been made, and good results are being obtained by several.

If the testimony of reliable parties may be accepted, the burners illustrated in accompanying engravings are accomplishing very creditable results in this direction. They are designed for attachment to the boiler front, preferably to the door itself, having flexible connections in order to allow the door to be opened and shut.

Burner B, figure 2, is thus described: Oil under pressure is admitted at the half-inch opening, as marked in the engraving, and led, as shown in the small section, through the cored passage to the jets, a, a. Through another half-inch pipe steam is brought to the intersection of these jets, spraying the oil as it passes from them, and at the same time inducing a current of heated air from the furnace itself through the larger openings shown.

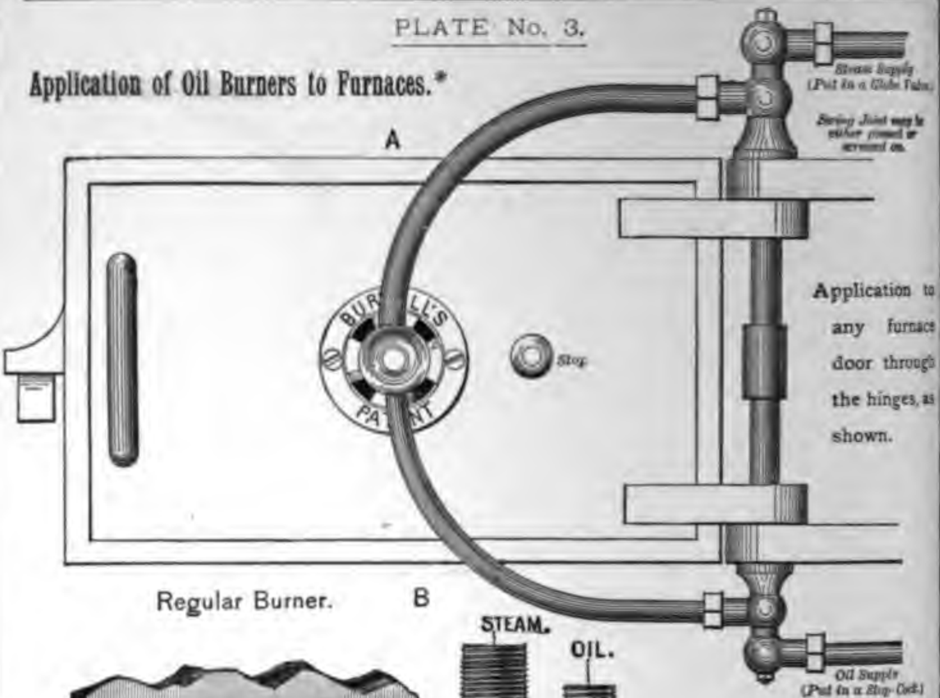
The oil issuing under pressure is sprayed by the steam and mingled with the hot air and gases from the furnace, and issues from a jet five eighths of an inch in diameter in a condition most favorable for instantaneous and complete combustion.

By changing the relative positions of the oil and steam jets, the character of the flame may be varied, giving a large, full flame near the burner and projecting it a distance of thirty feet, if desired; while by the manipulation of the steam and oil valves the flame may be reduced to a condition equivalent to a banked fire, supplying only sufficient heat to keep the closed boiler under a low pressure of steam.

PLATE No. 3.

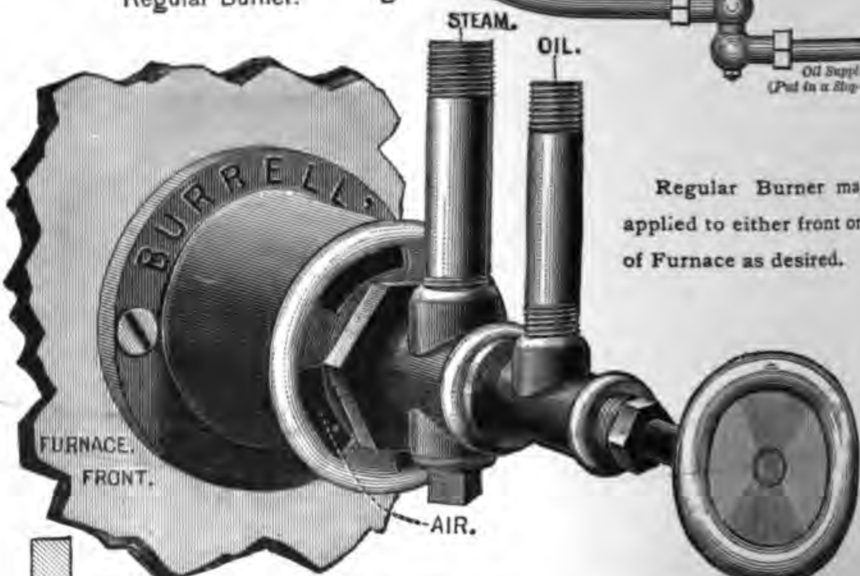
Application of Oil Burners to Furnaces.*

A



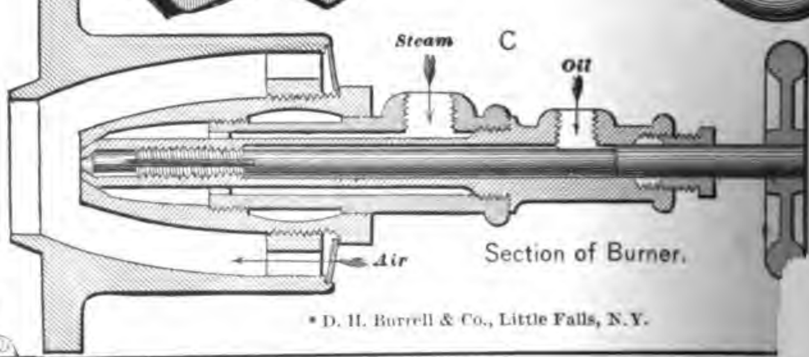
Application to any furnace door through the hinges, as shown.

Regular Burner. B



Regular Burner may be applied to either front or side of Furnace as desired.

C



Section of Burner.

* D. H. Burrell & Co., Little Falls, N.Y.

*BURRELL LIQUID FUEL BURNER.

The advantages of this new burner are as follows: —

1st. Its simplicity and adaptability to any furnace.

2d. Its construction so as to allow of its being readily taken apart.

3d. Its heating and superheating chambers, which insure steam that is more readily decomposed and oil thoroughly vaporized.

4th. The regulation of steam and oil vapor immediately at the nozzle and not at the valves, as in all other burners. (This we regard as our crowning achievement in means for the economic and perfect combustion of fuel oil.)

5th. The pipe connections so arranged as to suit any furnace.

6th. The admission of air can be regulated to the requirements of the oil and steam, thus giving an intense flame.

7th. It is made in one size only. All parts are duplicate and interchangeable.

8th. It may be used with or without other fuel, and may be so applied that oil can be burned one day and coal the next.

9th. Its design admits of several burners being arranged together for locomotive and marine use.

10th. Its internal construction has been especially arranged to thoroughly vaporize and economically consume the Standard Oil Company's fuel oil, which is recommended as the best and the cheapest.

And it may also be added that the price places it within fair reach of any desiring to change from solid to liquid fuel.

The various purposes to which the Burrell burner is applicable are many; and it can with safety be said that, wherever a clean, continual, and intense heat is required, it may be used to advantage.

The foregoing cut shows the interior construction and arrangement of the burners; and, by a study of the same, all the good features enumerated will be readily understood.

Attention is called to the following specific directions: The burners are sent out with steam and oil openings at the nozzle closed, as shown in the preceding cut. Without opening or altering this, make the attachment to the furnace as follows: —

Bore a one and a half inch hole through the furnace front (or plate, if used instead of a door) for each burner, and fit the nozzle of the casting into it, until the flange comes in close contact with the front or door; then mark through the [illegible] holes, and drill for three-eighths inch machine screws, tapping [illegible] out, and then securing the burner thereto.

PETROLEUM OIL FOR POWER.

A SUCCESSFUL PETROLEUM ENGINE.

For some time past, says the *London Standard*, a firm at Hull has been endeavoring to overcome the difficulties which have hitherto stood in the way of using the ordinary petroleum as motive power for engines. In this they have now fully succeeded, as was demonstrated by a petroleum engine which we inspected at their London offices. In this engine the oil is placed in a closed tank inside the foundation of the engine, and air is pumped into this tank until a pressure of about five pounds to the square inch is obtained. The air is then mixed with oil until it is formed into a vapor, after which it passes into a closed iron vessel or vaporizer, where it is heated, and from which it is admitted into the engine cylinder and ignited by means of an electric spark. The spark is obtained from a small primary battery capable of doing about thirty hours' work without attention, and which can be renewed at a very small cost. In starting the engine the vaporizer is heated for a few minutes, after which the necessary heat is obtained from the exhaust products of combustion while on their way to the chimney. The cylinder is water jacketed, the water being kept in circulation by a small pump.

After it has once been started the engine works automatically, preparing its own source of power, heating its charge, cooling its cylinder, and supplying its own spark for ignition. The great point here is that only ordinary petroleum is used, which, moreover, is entirely consumed, leaving no residue whatever, the combustion being complete.

The cost of working this engine, taking the oil at the present price, is stated to be a little more than a half-penny per hour.

The engine is simple in construction, and is well adapted for use where steam is inadmissible and coal gas not obtainable. It has been thoroughly tried and proved in practical work before being brought out.

It must be known to many of our readers that in this country much attention has been given to the production of a successful petroleum engine.

Geo. B. Brayton, of Providence, R. I., has done much good work in this line, has been granted many patents, and is probably still making improvements. A number of his engines have been put in small yachts.

A firm near Boston had a petroleum engine of several horse-power on exhibition at the Mechanics Fair in Boston last year.

A successful steam engine, with kerosene oil for fuel, is shown on next page.

*THE SHIPMAN OIL ENGINE—BOSTON MODEL.

This design is the latest production of the maker, is automatic in all its functions, and perfectly safe to operate anywhere. The engines are made to develop 1, 2, 4, and 6 horse-power. The boilers are made of wrought iron or steel, and tested to 300 pounds per square inch.

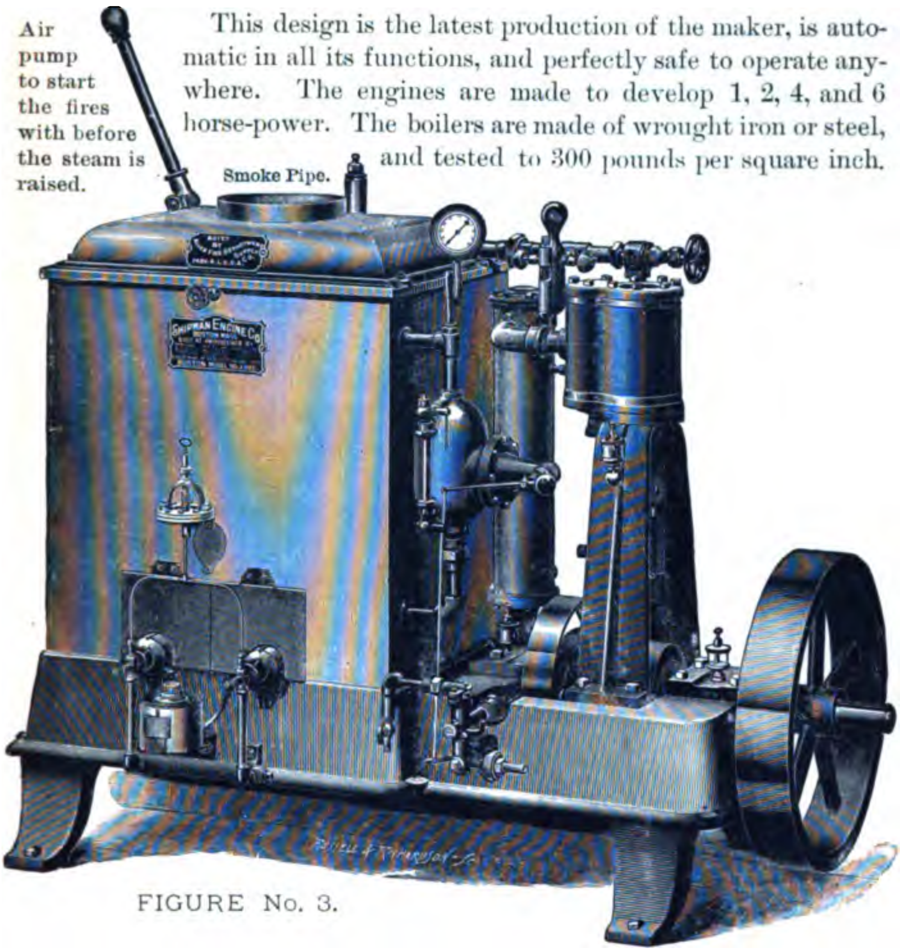


FIGURE No. 3.

The average amount of fuel consumed is two quarts of oil, costing from 3 *to 3½ cents per horse-power per hour.* By means of diaphragm valves, the oil supplied is so regulated as to preserve a constant steam pressure; while a float, controlling the action of the feed pump, insures the automatic maintenance of a constant water level.

So many of these engines are used for small boats or launches, that the company have put upon the market launches fitted with their engines, and having a speed of from six to twelve miles per hour. *The automatic features of the engine take care of the motive power, and allow a single person to successfully operate a boat.* The engines for the purpose are, of course, made with a reversing gear.

No additional insurance is charged for their use.

*The Shipman Oil Engine Co., 92 Pearl St., Boston, Mass.

PLATE No. 4.

STEAM LAUNCH, "THE SHIPMAN."

THE PROPERTY OF W. L. WELLMAN, ESQ., OF BOSTON, MASS.

DIMENSIONS.

27 feet long, 5 feet beam, draught, 22 inches. Engine, 2 horse-power. Speed, 8 miles per hour. Kerosene oil fuel, costing 3 to 3½ cents per horse-power per hour. Cost complete, from $700 to $800, according to style of finish.

CHAPTER XII

NATURAL GAS: TRANSPORTATION AND USE.

HAVING considered the conditions and results that may be derived from the proper burning of *coal* and *bitumen in their solid, powdered, and liquid* state, there remains but one other condition in which the product of coal may be found, or converted into fuel; viz., natural or manufactured gas; and, as the writer has had but one personal experience with gas fuel, the following chapters are made up of extracts from the scientific papers and items from several other sources.

* **History.** Natural gas was known to man in prehistoric times. The earliest historical reference to the Magi of Persia records them as worshiping the fires that blazed in the fissures of the Caucasus, at least six hundred years before the Christian Era.

Marco Polo, the celebrated traveler of the 13th century, refers to the burning jets of the Caucasus, and those fires were known to the Russians as continuing in existence since the army of Peter the Great first wrested this region about the Caspian from the modern Persians.

In the confines of Persia, in the south of France, and in our own western and middle States burning springs have long been known. Even the utilization of natural gas for purposes of the mechanic arts has been successfully attempted in China, where by pipes of bamboo it has been conveyed from natural wells to suitable furnaces, where by means of terra cotta burners it was consumed.

In the United States the phenomena of burning springs were observed by the earliest settlers west of the Alleghenies. The localities that have been most celebrated for their gas wells are: Fredonia, Chautauqua county, New York; Wilcox, Elk county, Pennsylvania; Rochester, Beaver county, Pennsylvania; Burns well and Harvey well, Butler county, Pennsylvania; Leechburg, Westmoreland county, Pennsylvania; Sheffield, Warren county, Pennsylvania; Allegheny county, Pennsylvania; Erie, Erie county, Pennsylvania; Painesville, Lake county, Ohio; East Liverpool, Columbiana county, Ohio; Gambier, Knox county, Ohio; New Cumberland, Hancock county, West Virginia; Burning Springs, Wirt county, West Virginia.

* *Scientific American*, July 11, 1885.

The Origin of Natural Gas and the Regions Where it is Found. Of the origin of natural gas, there seems to be no reasonable doubt. It arises from the decomposition of forms of animal and vegetable life imbedded in the rocks in suitable situations.

The gas is not believed to be generated continuously, but merely to be stored in porous or cavernous rocks overlaid by impervious strata. When these collections are tapped, the gas is set free, but a new supply is not being formed to take its place.

The position in which gas is found is very variable, depending on the force of gravity and the position of the porous strata in which the gas is confined.

The region in which gas is found is practically embraced in that portion of Pennsylvania west of the Allegheny Mountains, and extending into Ohio, New York, and West Virginia a short distance. It is also stated to have been found to a limited extent in Illinois and Kansas.

"In the great petroleum region of the Appalachian system the accumulations of gas are often found upon the anticlinals in the pebble conglomerates and sandstones which hold petroleum; while at a still lower level in the troughs of the synclinals salt water occurs. In a general manner, with the sea level as a datum line, the Venango and Bradford oil sands lie sloping with a gentle inclination, the southwestern edges submerged in salt water and the northeastern edge saturated with gas at an enormous pressure. Not the slightest evidence that volcanic action has ever obtained in that region has been observed; but all the geological features lead to the conclusion that petroleum and natural gas have been produced by the same cause. That volcanic action is not that cause, is further shown by analyses that have been made of natural gas from different localities.

"In the gases from burning springs and wells carburetted hydrogen predominates, accompanied by other products of *distillation*. In the gases from solfataras (of volcanic origin) carbon dioxide predominates, accompanied by other products of the *combustion* of carbon. The distillation of strata rich in organic remains, when invaded by metamorphic action, has doubtless produced the inflammable gases of burning springs and gas wells in a manner analogous to and often simultaneous with the production of petroleum."

The Discovery of Natural Gas in the United States. "The record of natural gas in this country is not so complete as that of petroleum, but we learn that an important gas spring was known in West Bloomfield, N. Y., seventy years ago. In 1864 a well was sunk to the depth of three hundred feet upon that vein, from which a sufficient supply of gas was obtained to heat and illuminate the city of Rochester, twenty miles distant, *it was supposed*. But the pipes which were laid

for that purpose, being of wood, were unfitted to withstand the pressure, in consequence of which the scheme was abandoned; but gas from that well is now in use as an illuminant and as a fuel, both in the town of West Bloomfield and at Honeoye Falls. The village of Fredonia has been using natural gas in lighting the streets of the city for a period of thirty years.

The use of natural gas in Fredonia was begun in 1821, when experiments were made to determine its illuminating value; and it was introduced into a few of the public places, among which was the hotel that then occupied the site of the Taylor House, and which was thus illuminated when Lafayette passed through the village in 1824.

First Use of Natural Gas. On Big Sewickley Creek, in Westmoreland county, Pennsylvania, natural gas was used in evaporating water in the manufacture of salt thirty years ago, and gas is still issuing at the same place.

Natural gas has been in use in several localities in Eastern Ohio for twenty-five years, and the wells are still flowing as vigorously as when first known. It has also been in use in West Virginia for quarter of a century, as well as in the petroleum region of Western Pennsylvania, where it has long been utilized in generating steam for drilling oil wells.

Professor Wurtz, as long ago as 1869, urged the use of natural gas in the region of which the great gas well at West Bloomfield, Ontario county, N. Y., was the centre.

In a discussion before the Lyceum of Natural History of New York, October, 1871, he gave the quantity of gas sent out by this well as five cubic feet per second, and the composition 82½ volumes per cent marsh gas, 10 per cent carbonic acid, 3 per cent illuminating gases of the olefine group, estimating its heating power equal to fourteen tons of anthracite coal per day, and discussing at length the question of carrying the gas under heavy pressure great distances for use as a heating and lighting agent. Professor Wurtz indicated five or six beds running across New York State, "lying deep enough and thick and porous enough" to pour out combustible gas when tapped. And he repeated a statement that he made long before editorially in the columns of the *Gas Light Journal* that "It may be accepted with implicit confidence as a fact, that there are vast districts of country throughout the United States in which, by judicious exploration, an immense number of such fountains of natural gas may be developed, furnishing a fuel which raises itself from the mine, and which may be made to transport itself up hill and down dale, to any point required, independently of seasons and circumstances, miners' strikes and railroad strikes to the contrary notwithstanding. A future lies before this new art of developing the gifts

of Mother Nature, big with a promise, for which even the wondrous history of American petroleum production has furnished no parallel."

* **Chemical Composition.** Natural gas consists, wherever found, mainly of marsh gas or light carburetted hydrogen. It also is liable to contain, in some localities, hydrogen, nitrogen, carbonic acid and oxide, and other constituents in small quantities. Its composition varies in the same well at different periods.

The following is the analysis of gas obtained from the well of the Fuel Gas Company in Murraysville: Hydrogen, 19.56; marsh gas, 78.24; oxygen, 2.20.

Gas from Leesburg, Pa., analyzed by S. P. Sadtler, shows hydrogen, 4.79; marsh gas, 89.65; ethane, 4.39; carbonic acid, 0.35; carbonic oxide, 0.26; illuminating hydrocarbons, 0.56, with traces of propane.

From West Bloomfield, N. Y., by H. Wurtz: Marsh gas, 82.41; carbonic acid, 10.11; nitrogen, 4.31; oxygen, 0.23; illuminating hydrocarbons, 2.04.

* **Comparison of the Heating Powers of Natural Gas and Other Fuels** by C. E. Hequembourg. Results of many average tests of gas from Bradford, Pa. show: —

1st. Compared with coal gas, natural gas exceeds it in calorific value 33⅓ per cent.

2d. With crude, ordinary, and best methods of combustion, the calorific value of natural gas compared with coal under best conditions is: —

With crude method	20 cubic feet = 1 lb. coal.
With ordinary method . . .	11.29 cubic feet = 1 lb. coal.
With best method	8.92 cubic feet = 1 lb. coal.

* **Heating Capacity.** A thorough test was made last spring by a committee appointed by the American Society of Mechanical Engineers to ascertain the relative heating capacity of natural gas and of Pittsburg coal. It was found that 1 pound of coal evaporated 9 pounds of water from a temperature of from 60° to 62°, and 1 pound of gas evaporated from 20 to 31 pounds of water under similar conditions. Practically 1 pound of gas is equal to 2 pounds of coal.

There are 23½ cubic feet of natural gas in 1 pound's weight, or 42½ pounds in 1,000 cubic feet, the commercial unit.

S. A. Ford, chemist of the Edgar Thompson Steel Works, at Pittsburg, Pa., has made a number of analyses of natural gas, with a view of estimating its heating power as compared with coal. He finds that 1,000 cubic feet of an average gas contains 833,766 heat units, and weighs, in round numbers, 38 pounds. Now, 38 pounds of carbon contain 549,505 heat units; so that it will take 57.25 pounds of carbon to contain the same number of heat units as the 1,000 feet of natural gas.

* *Scientific American* Supplements.

Estimating that coke contains 90 per cent of carbon, we have 62.97 pounds of coke, equal in heat units to 1,000 feet of natural gas. If a ton of coke, or 2,000 pounds, cost $2.50, then 62.97 pounds will cost 7.87 cents, or 1,000 cubic feet of gas is worth 7.87 cents for heating.

Economic Localities and Production. The most important economic locality is that in the immediate vicinity of Pittsburg, which supplies that city with the fuel for the vast iron and glass works and for numerous private dwellings. There are six natural gas companies in the city managing 107 wells, and supplying the gas through over 500 miles of pipe, of which 232 miles are situated in the city proper. The total area of pipe leading into the city of Pittsburg is given as 1,346,608 square inches, and the total capacity of the lines is estimated at over 250,000,000 cubic feet of gas per day.

The largest company is the Philadelphia Natural Gas Company, which supplies over 500 manufactories and over 7,000 dwellings with the entire amount of fuel consumed.

* **Fostoria, Ohio.** The region about Fostoria is organized under the Northwestern Gas Company, and controls a large territory. It supplies the city of Toledo (which uses no other fuel) through pipes 30 miles long, and Fremont and other towns. The gas, when it comes from the well, is about the temperature of 32° Fahr., and the common pressure is 400 pounds to the square inch.

The Ohio area of gas is between 2,000 and 3,000 square miles.

The claim of the Indiana area is that it is 20,000 square miles, but the geologists make it much less.

The speculation in real estate has been perhaps without parallel in the annals of the State ; and, as usual in such cases, now there is a lull waiting for developments. But these have been almost as wonderful as the speculation.

Findlay was a village in the black swamp district — one of the most backward regions in Ohio. For many years there had been surface indications of gas, and there is now a house standing in the city which used gas for fuel forty years ago. When the first gas well was opened ten years ago, the town had forty-five hundred inhabitants. It has now probably fifteen thousand ; it is a city, and its limits have been extended to cover an area of six miles long by four miles wide. This is dotted over with hastily built houses, and is rapidly being occupied by manufacturing establishments.

The city owns all the gas wells, and supplies [illegible] to factories and private houses at the simple cost of maintaining [illegible] vice pipes.

* C. Dudley [illegible] *Harper's Month*[illegible]

This immediate region has an oil field contiguous to the gas, plenty of limestone (the kilns are burned with gas), good building stone, clay fit for making bricks and tiles, and superior hard-wood forests.

The cheap fuel has already attracted here manufacturing industries of all kinds, and new plants are continually being made. Among the most interesting of these are the works for making window and table glass.

Gas Wells. * The regions in which natural gas is found are for the most part coincident with the formations producing petroleum. This, however, is not always the case; and it is worthy of notice that some districts which were but indifferent oil producers are now famous in gas records. The gas driller, therefore, usually confines himself to the regions known to have produced oil, but the selection of the particular location for a well within these limits appears to be eminently fanciful.

The more scientific usually select a spot either on the anticlinal or the synclinal axis of the formation, giving preference to the former position. Almost all rock formations have some inclination to the horizon, and the constant change of this inclination produces a series of waves, the crests of which are known as anticlines and the troughs as synclines.

The site having been selected, the ordinary oil-drilling outfit is employed to sink a hole about six inches in diameter until gas is reached. In the neighborhood of Pittsburg this is usually found at the depth of *thirteen hundred to fifteen hundred feet*, in what is generally known as the third oil sand, a sandstone of the Devonian period. When the driller strikes gas, he is not left in any doubt of the event; for, if the well be of any strength, the gas manifests itself by sending the drill and its attachments into the air, often to the height of a hundred feet or more.

The plant at the well is much simpler than one would suppose. An elbow joint connects the projecting end of the well piping with a pipe leading to a strong sheet-iron tank. This collects the salt water brought up with the gas. Ordinarily about half a barrel accumulates in twenty-four hours. A safety valve, a pressure regulator, indicator, and a blower complete the outfit. When the pressure exceeds a prescribed limit, the valve opens and the gas escapes into the blow-out. This is usually thirty feet high or more, and the gas escaping from the top is either ignited or permitted to discharge into the atmosphere. The pipe line leading from the tank to the city is of course placed underground. Beyond a little wooden house, the blow-off, and a derrick, the gas farms differ but little in appearance from those producing less valuable crops.

* *Scientific American*, Feb. 27, 1886.

The pressure of the gas at the wells varies considerably. It is generally between one hundred and three hundred and twenty-five pounds. As much as seven hundred and fifty pounds per square inch has been measured, and in many cases the actual pressure is greater than this; but as a rule it is not permitted to much exceed twenty atmospheres in any receiver or pipe. The maximum pressure in lines of the Philadelphia Company is three hundred and forty pounds. The supply of Pittsburg is largely in the hands of this organization, and drawn from its wells at Tarentum and Murraysville.

Transportation and Pipe Lines.* The pioneers in the piping of natural gas for mechanical purposes were an organization of prominent Pittsburg manufacturers and practical oil men. It was organized in the summer of 1875, and gas was turned on to the line in the fall of 1876. The wells were situated in Clinton Township, Butler county, Pa., and the mills supplied were those of members of the firm situated in Etna and Millvale, suburban boroughs of Pittsburg on the Allegheny river and distant from the wells seventeen miles. It was not, however, until 1884 that the fuel gave any indication of the role that it was afterwards to fill.

The question of pipeage is one of immense importance, and, with increased knowledge of the best conditions for securing an even flow of gas, becomes even more prominent; for the lines are being rapidly extended in length, and it is asserted by many practical men that they will some day reach the seaboard.

The pipe lines of the Philadelphia Company vary in diameter from 4 to 10 inches. The Chartiers Company, however, have one line of 16 inches in diameter. In the city the distributing mains are from 4 to 24 inches. The general tendency is to an increase of diameter, in order to lessen the friction and enable the supply to meet any unexpected demand without interfering with the usual flow. The average diameter of the city mains may be stated as 16 inches. The distributing pipes vary from 4 to 10 inches.

The pipe lines have to be laid with the greatest care, to withstand these high pressures and avoid leakage. They cost from $2,000 per mile for pipes from 4 to 8 inches up, to $30,000 for 24 inches. The Philadelphia Company alone has about 375 miles of pipes 4 inches in diameter and over.

Every day line walkers go over the whole line, and submit reports of its condition to the central office. In addition t[illegible] this daily inspection, a man is sent by the company to every fire, [illegible] is his duty to turn off the gas from the burning building and fro[illegible] may be in immediate danger.

* For diagram of the pipe lines, [illegible]

The question of pressure throughout the lines is one of vital importance, and its regulation demands constant attention. For this purpose valve houses or stations, to the number of 22, have been established at various points on the line as well as in the city, and at Tarentum, Murraysville, and Dick Farm. At each of these stations the pressure is registered every hour. The company has four telegraph lines of its own, of a total length of about eighty miles, and each station is connected with the central station on Penn avenue.

The practical questions of leakage, dangers from explosions, and controlling the gas under high pressure have been solved by the Pennsylvania companies. The following are results given to the public by the Philadelphia Company, Pittsburg, Pa.:—

"It being practically impossible to make a series of joints in the ordinary way that could be depended upon to remain gas-tight, the attention of inventors and engineers was then directed to devising and perfecting suitable safety appliances, first, to make the joints more secure, and second, to confine within certain limits any escaping gas, and to conduct it through auxiliary pipes to places where it could escape safely. Such a system was perfected and applied to more than one hundred miles of main pipes in Pittsburg and Allegheny City with most gratifying results. By its use the actual loss of gas by leakage is less than 1 per cent, and the danger of explosions from this cause is practically overcome."

Cost of Pipe Lines. In an article by Geo. H. Christian, in the *Scientific American*, the author estimates the cost of a line of wrought iron or steel pipe, 300 miles in length, and delivering 225,000,000 cubic feet daily, with an initial pressure of 300 pounds to the square inch, at $16,000,000, including right of way, gas property, drilling of wells, and city pipe system.

"At first sight the sum of $16,000,000 might seem to be so great as to preclude capitalists from investing in such a scheme; but, when we estimate the receipts from the sale of this gas, we will probably change our minds.

"One thousand feet of natural gas contains 1,000,000* heat units; 1 bushel or 50 pounds of hard coal, 1,200,000 heat units. In burning gas for domestic purposes, you realize 50 per cent more of its heat than you do in burning coal, or your gas would be equal to 100 pounds of hard coal. Hard coal in New York City or Philadelphia is worth $5 per ton, or 25 cents per 100 pounds.

*Discrepancies in the estimate of the heating power of one thousand cubic feet of gas by different authorities, are due probably to difference of pressure; the density, and hence the heating capacity of a given volume of the gas, being proportional to the pressure.

See Table No. 3, page 36.

NATURAL GAS IN INDIANA.*

"Some idea of the vast importance of the natural-gas interest of Indiana may be gained from a study of the report recently made by the State Geologist. He has been collecting all the information he could possibly obtain concerning the subject, and from the results of his investigations we learn that the gas area of Indiana is 165 miles in length by 65 miles in width; altogether there are 381 paying wells in this district. The entire flow of gas is placed at 600,000,000 feet, of which it is calculated something like 1,000,000 cubic feet go to waste. The average flow of gas from each well is stated as being about 150,000 cubic feet. The report further mentions the fact that, during the past two years, 79 manufactories have been located in Indiana, simply and solely because of the fact that they could obtain this fuel. Their combined capital is stated, in *Fire and Water*, as reaching $4,500,000, and it is said that they will employ 5,800 men."

The most active development of natural gas in Indiana at present seems to be in the vicinity of Muncie, as described in the following article from the Boston *Herald* of March 6, 1889:—

"'MUNCIE, THE NEW ELDORADO.—Muncie is located on the beautiful and historic White River, and two years before the discovery of natural gas contained 7,000 people. To-day the population exceeds 14,000.

"'Muncie is called the "Natural Gas City of the West." She far outstrips her rivals in enterprise, location, and quantity and quality of natural gas. She has the finest Court House in the State outside of Indianapolis, and her schools are models of perfection. Twelve churches, five hotels, rows of brick and stone blocks, paid fire department, water-works and perfect sewerage system, macadamized streets, and miles of stone pavements, fringed with lovely maple trees, give comfort and attractiveness to the city's appearance.

"'Thirty-three mighty gas wells within a radius of two miles pour forth over 100,000,000 cubic feet of natural gas per day, equal in heating and lighting power to 5,000 tons of coal per day.

"'The minimum cost of coal is $2 per ton, making the daily capacity of Muncie wells equal to $10,000 worth of the best fuel in existence, and amounting to the enormous sum of over $3,000,000 per year.

"'It is estimated that an ample supply of gas is found or manufactured beneath each 10 acres to support a well, which would allow 64 wells to a section, or 2,304 wells to the township in which Muncie is located.

"'Eighteen large factories have been located in Muncie within the last 18 months, and new ones are seeking the field every week. Free fuel and land are given to manufacturers, thus insuring a saving of from $5,000 to $40,000 yearly to each manufacturer locating in Muncie.

"'Two manufacturers now there inform us that they are saving from $30,000 to $40,000 each annually. Houses are furnished with heat, fuel, and light the year round for from $4 to $16 per year.

"'A belt line of railroad skirts the town, and runs through the property of the company, giving manufacturers direct communication with three trunk lines of railroad; namely, the C. C. & I. or "Bee" line, the Lake Erie & Western, and the Fort Wayne, Cincinnati & Louisville, which crosses all east and west trunk lines.

"'A company with a capital of $2,000,000, with ex-Governor Leon Abbot, of New Jersey, as President, has been formed under the name of the Muncie Natural Gas Land Improvement Co., for the purpose of buying, selling, leasing, improving lands; erecting buildings, houses, and other structures; sinking wells; obtaining, using, storing, piping, and selling natural gas, oil, or other substances to be used for the purpose of fuel and light.'"

(For other localities, see page 171.)

* The *Boston Herald*, 1889.

THE WASTE OF NATURAL GAS, IMPERFECT HANDLING, ETC.*

Considerable comment has been occasioned by the circular recently sent by the Philadelphia Company to the manufacturers who use gas, requesting them to prevent, as far as possible, the waste of fuel at their works. The request, the circular suggests, can be best carried out by the managers of the various plants instructing watchmen, furnace-men, and other employés to shut off the gas from all furnaces and other parts of the mills when the latter are not running. It is asserted that the circular referred to is proof that the natural-gas supply is failing, that Pittsburg's mills and manufactories must soon return to the use of coal, and that even private consumers will before long find the gas inadequate.

For over a year past the Philadelphia Company officials have been measuring the consumption of gas, making tests on improved furnace appliances, and otherwise investigating the fuel waste in the various mills. From the investigations in this district, figures have been deduced showing that a large proportion of the gas is wasted here. As an illustration, we append the following figures, given by the Philadelphia Company, showing by exact measurement the amount of gas *required*, and the amount *used* to make a ton of iron in a puddling furnace of the ordinary style. *Record from five leading Pittsburg mills.*

Gas consumed in actual work per ton of iron as above — average, 37,496 ft.
Gas used during the whole time per ton of iron as above — average, 52,786 ft.

The quantity of gas *used* during the whole time (52,786 feet), as compared with the quantity *consumed* during actual work (37,496 feet), shows the waste occasioned by burning the gas too high between the heats, excessive use of the gas in keeping furnaces hot between turns, and the thousand and one ways in which careless employés waste the fuel because it comes into the mill without hauling. When the Philadelphia Company saw the loss occasioned, an effort was made to introduce furnace improvement, with the idea of economizing the use of the gas. In one mill great care in handling the gas had brought the consumption down to *twenty-one thousand five hundred and thirty-five* in making a ton of iron; improvements further reduced the consumption to *fifteen thousand nine hundred and fifty-two.* The best result yet attained was when a ton of puddled iron was produced in an improved furnace with an expenditure of *twelve thousand one hundred* cubic feet of gas.

Representatives of the gas companies say that they have visited factories when no one was at work, yet the gas was burning at a full head, because "the watchman forgot to turn it down."

On the whole it is estimated that at least 50 per cent of the gas now used in the Pittsburg mills is lost through ineffective methods and bad management.

* *Scientific American*, March 2, 1889.

PERMANENCY OF THE NATURAL GAS.*

Petroleum and natural gas, which, for the moment, play so distinguished a role in the history of the Pittsburg region, are merely supplementary to its prosperity—a temporary, a fugitive condition to its wealth; and, although inseparable from the main features of the carboniferous geology, yet to be treated entirely apart from coal in our forecast of the future. They make, indeed, a most important chapter in our description of the geology of the region; but that chapter will be seen in the course of time to be merely an appendix to the book. They go together into the chapter, for oil and gas are but two aspects of one and the same substance, originally united, and still in combination—the one a product of the other, but neither of them holding any natural relationship to coal. The oil and gas obtained from cannel coal and the coal shales are not the same as the oil and gas which spout and roar from the bore holes.

As gas is a direct product of petroleum by spontaneous evaporation, the life of the gas production will be limited by the amount of the volatile elements, held in a definitely limited quantity of petroleum existing underground; and, therefore, those who are producing and using this enormously valuable mineral substance should take every precaution to avoid its waste, seeing that it is bound to come to an end.

NOTE.—The most noteworthy point in the composition of well gas is its frequent and rapid variation.

It has been an embarrassment to some consumers that there was not sufficient steadiness in the heat produced. One day the required heat was obtained at a certain pressure; the next day the same degree of heat could not be obtained from the same amount of gas.

Analyses of two samples of gas from the same well have exhibited the startling fact that at one time the gas is composed of only 35 or 40 per cent of the marsh-gas element, and at another time 70 or 80 per cent or even more.

Of course the heating power falls as the percentage of the ultra-hydrogen element rises. The discovery is so recent that no account of the causes at work underground can be given.

When the natural-gas production comes to an end, it seems safe to say that a vast manufacture of artificial gas will take its place, and that the artificial gas will be less variable in its heat-producing quality.

I take this opportunity to express my conviction in the strongest terms that the amazing exhibition of oil and gas which has characterized the last twenty years, and will probably characterize the next ten or twenty years, is, nevertheless, not on y geologically but historically a temporary and vanishing phenomenon—one which young men will live to see come to a natural end.

For I am no geologist if it be true that the manufacture of oil in the laboratory of nature is still going on at the one thousandth part of the rate of its exhaustion.

And the science of geology may as well be abandoned as a guide, if events prove that such an exhibition of oil in Western Pennsylvania, as our statistics exhibit, can continue for successive generations. It cannot be. There is a limited amount. Our children will merely and with difficulty drain the dregs.

I hold the same opinion respecting gas, and for the same reasons, with the difference merely that the end will come sooner and be all the more hastened by the multiplication of gas wells and of the fire boxes and furnaces to which it is led.

The exhaustion of the mineral coal of the region is, on the contrary, a practical impossibility. Every cubic yard of coal may be taken as a ton. Every square mile of a horizontal coal bed may be said to yield a million tons of coal to every foot of coal bed; that is, for a ten-foot bed, ten million tons, or, allowing one half for waste, five million tons. The Pittsburg region has an outspread of the Pittsburg coal bed *fifty miles long by fifty miles wide within the limits of the State.*

* From Report of J. P. Lesley, State Geologist of Pennsylvania, February, 1886.

APPLICATIONS OF NATURAL GAS.

At Rochester, Pa., and East Liverpool, O., the gas is burned in enormous quantities in glasshouses. At Gambier, O., and New Cumberland, W. Va., the gas is burned in a manner to produce lamp black. The gas of the Burns, Harvey, and Leechburg wells is, or has been, used in puddling iron. The latter was found particularly valuable in the preparation of the quality of pure rolled iron used for tin plate. Bradford and other towns in the oil regions are mainly heated and lighted with natural gas from the oil wells, and in some instances from wells drilled on purpose to obtain gas.

The gas of the Neff and other wells is utilized largely for the production of lamp black. This black is very pure, and is well adapted to fine printer's ink and the like. It is also used in the preparation of lithographic ink.

At New Cumberland, W. Va., Messrs. Smith, Porter & Company use natural gas for burning fire brick. The gas from one well furnishes fuel for nine brick kilns, three engines and ten furnaces in the drying house, with fuel and lights for several dwellings, besides a large excess which is burned at the end of an escape pipe. They produce fifty-five thousand brick daily.

The gas from wells from many of these localities has been made very useful for technological purposes. Many gas wells have been drilled for private houses and manufacturing establishments. For the latter purpose, where large quantities are used, the yield of the wells runs down in a few years. At Painesville, O., gas wells are bored for private dwellings, and the gas is often used for heating as well as illuminating.

REVENUE FROM THE SALE OF GAS.

"If we should sell this gas for 12½ cents per 1,000 feet, it would reduce the cost of fuel to consumers 50 per cent. The daily receipts from the sale of 2,000,000 cubic feet of gas would be $25,000, or $10,000,000 per year. Allowing 15 per cent on investment, you have remaining for yearly running expenses, improvements, repairs, and sinking fund, $7,750,000.

"You may ask, how is it that you figure such a large revenue, when in Pittsburg their total yearly revenue is but $2,500,000? The facts are, in Pittsburg soft coal is used, and sells for $1.25 per ton as against $5 in New York.

"If you should pipe from Findlay Field to Chicago, you could not realize over 10 cents per 1,000 cubic feet; but, even here, $8,000,000 per year revenue should pay handsomely.

"Cleveland and Cincinnati are both nearer the gas territory, and the cost of plant very much less. These places must very soon avail themselves of this cheap fuel.

*MAKING STEEL AND IRON.

"A demonstration of the value of gas fuel and radiated heat has recently been made by James Henderson, at McKeesport, Pa., where he erected a furnace for heating scrap iron by burning natural gas.

"In the construction of this furnace six one-inch gas pipes are placed at one end, which deliver the gas into a large expansion chamber, the quantity being regulated by valves and a blast gauge. This gas expands greatly in the chamber, and travels from the open end of the chamber to the air tuyeres, situated at the end of the gas passage, where a measured quantity of cold air is delivered to the gas, which has become highly heated in its passage to meet the air by the heat radiated by the burning of the preceding gas. The heat is probably 3,000° Fahr. before it meets the air, which is delivered diagonally forward across the gas flue, so that its focus is but six inches from the heating chamber. The gas passes through the air, and is so thoroughly mixed that its combustion is perfect by the time that the flame, thus produced, enters the heating chamber, and there is no smoke anywhere; the chimney top prevents the appearance of clear radiated heat observable out of doors.

"The bed or hearth in the heating chamber is 20 feet long, 4 feet 6 inches wide, and 5 feet from hearth in the clear; the flame passes clearly above the iron on the hearth, and about 1 foot clear of the roof to the uptake. Iron charged simultaneously at each of the 4 doors of the furnace becomes as quickly heated at the uptake as where combustion takes place, or in 5 minutes 250 pounds at each door is at a welding heat and ready to draw; so that 5 piles may be heated every 5 minutes of 250 pounds each. By charging at each door consecutively a pile may be drawn every minute, or 1,440 pounds, equal to 180 tons in 24 hours. It is claimed for this furnace that if air be excluded from passing through the doors, except when drawing and charging the piles (which is not the case at McKeesport), nearly all the waste of 10 per cent usual in heating iron may be saved. The economy of fuel is very great, as the production is from ¾ of that now generally used for heating, with 7 *times greater output* from the less quantity.

"Wrought iron exposed on the hearth of this furnace in large lots begins to melt in 10 minutes, becoming mushy, or so soft that it cannot be balled except it is first cooled by throwing water upon it, indicating that the furnace will be economical for making open hearth steel — its cost not being over $3,000 to make it, with a bed to convert 20 tons.

"There are no regenerators, nor is heated air used, nor is there any additional expense *in heating the gas.* This furnace dispels the ill[illegible] that regenerators are essential to high temperatures for steel, and shows that steel may be made for *about ⅙ of the cost* [illegible] *now incurred.*"

* *Scientific American*, Jan. 26, 1889.

*THE MANUFACTURE OF WINDOW GLASS BY NATURAL GAS.

"There is probably no industry among the many that have been benefited by the utilization of natural gas in which the results have been so marked as in the manufacture of glass. For a number of years past American glass has been undoubtedly inferior to the product of European factories, and has consequently occupied but a secondary position in the estimation of American builders and architects. The foreign manufacturers, and particularly those of France and Belgium, have hitherto manifested a superior dexterity in the handling of their materials. They seem to have held the secret of either neutralizing the effect of impurities in their fuel or of burning it in such a manner as to get the minimum disadvantage from their presence. This has been due partly to the greater experience in the industry and partly to the better construction of their furnaces. In some of the more perfect plants, crude fuel has been abandoned and manufactured gas used instead, thus giving them in advance the advantages of natural gas, with the important exception, however, of its cheapness and almost total freedom from sulphur. These circumstances make imported glass synonymous with best quality.

"That these conditions have now so far changed that our own manufacturers can compete with the best foreign producers, and can even honestly claim certain points of superiority for the home product, is a subject for hearty congratulation. The improvement has been effected by the more complete mechanical appliances now at our command, *but the most potent influence must be ascribed to the use of natural gas.*"

Perhaps the best description of the revolution that has been effected by the use of natural gas is that by Mr. Andrew Carnegie in 1885: —

"In the manufacture of iron, and especially that of steel, the quality is also improved by the pure new fuel. In our steel-rail mills we have not used a pound of coal for more than a year, nor in our iron mills for nearly the same period. The change is a startling one. Where we had formerly *ninety firemen* at work in *one boiler-house*, and were using *four hundred tons of coal per day*, a visitor now walks along the long row of boilers, and sees but *one man in attendance.* The house being whitewashed, not a sign of dirty fuel of former days is to be seen, nor do the stacks emit smoke. In the Union iron mills our puddlers have whitewashed the coal bunkers belonging to their furnaces. Most of the principal iron and glass establishments in the city are to-day either using the gas fuel or are making preparations to do so. The cost of coal is not only saved, but the great cost of firing and handling it, while the repairs to boilers and grate bars are much less."

* *Scientific American*, March 20, 1886.

FOR DOMESTIC USES.

*"The cost of natural gas for fuel in dwelling-houses is less than coal, even in Pittsburg, where the price of the former is higher, and the latter lower than elsewhere. The companies do not measure the gas, but make a contract to supply a family for a given sum a year. In Pittsburg the price for *heating* and *lighting* every apartment in a twelve-room house, and of furnishing all the fuel for *cooking purposes*, is from $70 to $90 per annum. *But as the gas is not a favorite illuminant, the price paid is much less.*

"Economy is not the only thing that makes the use of natural gas popular. It is an ideal fuel; it requires no especial and expensive fixtures for its use. If a house was previously heated by a furnace or by steam, the natural gas adapts itself to the existing apparatus. If stoves or open fireplaces were used, they do their work better with natural gas than with wood or coal.

"The gas is conducted to the heating apparatus through pipes similar to those used for artificial illuminating gas. The fire box of the furnace or stove may be partially filled with pebbles about the size of the coal formerly used, in order to distribute the flame. In the bottom, just below where the gas is discharged in the fire box, the pipe passes through an iron sphere about as large as a man's fist and pierced with a number of holes each half an inch in diameter. As the gas passes through this, it is mixed with air, the proportion being regulated by the number of holes left open. The amount necessary to insure perfect combustion and the greatest degree of heat is generally *one-fifth gas and four-fifths air.*

"The fire in an open grate or cooking stove is arranged in the same way. If wood was formerly used on the hearth in the fireplace, artificial sticks made of clay or porcelain are substituted, the aerated gas is conducted beneath them and there lighted. The flames surround and blaze above the artificial sticks with a beautiful effect, and send forth a genial heat in the room.

"The natural gas, when properly mixed with air, burns absolutely without smoke, dust, or odor.

"Beautifully decorated tiles used in the construction of a fireplace are not stained or soiled after a whole year, although they may have been in constant contact with the flames of the burning gas for months. The most delicate furniture and fabrics are not injured by being kept in a room heated by it. In fact, they retain their original freshness and beauty as though they had been carefully protected by a covering."

*Z. L. White in *American Magazine*, Oct., [illegible]

OIL AND GAS FOR FUEL UNDER BOILERS.

We have reports from one or two parties who have tried oil for fuel under boilers in the place of coal. At Dansville Sanatorium, New York, oil was tried in the place of coal.

The boilers were the horizontal tubular pattern, about forty horse-power. The oil was fed to the burners (of the steam jet pattern) by gravity, in the usual way. No effort was made to secure a combustion chamber by covering the grate or using fire brick.

The result was unsatisfactory with oil at less than 3 cents per gallon; the loss or deficiency was $40 to $50 per month, the duty or work being the same, the price of coal being $2.75 per ton of two thousand pounds.

Now, I do not regard this as the natural or necessary result, but only as proving that the better fuel was the worse managed. Indeed, the finer the fuel, the better must it be treated.

In burning coal, the best results are obtained using a fine fuel and a mechanical stoker; the fuel and air to combine with it are regularly and automatically supplied, no fire doors are opened, and the temperatures of the fire chamber are always high. Thus efficiency and economy are secured. See section on boilers.

A reversal of this last unfavorable experiment with oil fuel was obtained at the Michigan Carbon Works, Detroit. See pages 159 and 160.

One other condition should be referred to; that is, the effect of the removal of the radiant heat, which is available in domestic and other coal-burning boilers. The effect of a bed of solid live coal on the heating surfaces is very great, amounting, I think, to one third the total work done by the fuel. In heating surfaces this effect is seen to be (table No. 9 and diagram No. 16) nearly one half. Now, in substituting gas, this potent factor is almost lost, unless the gas is introduced below a bed of refractory materials, that may serve as a mixing chamber, and that may, becoming highly heated, give out heat by *radiation, as did the solid fuel.* Practice has demonstrated that this is the essential and successful condition of the application of gas fuel to boilers and heating surfaces of every description.

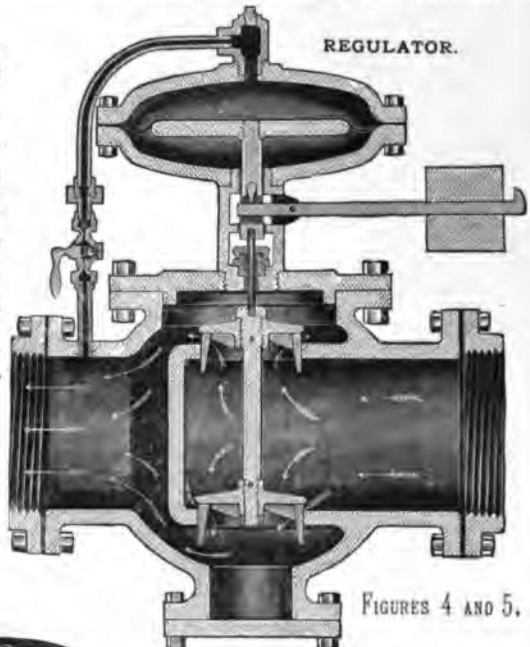
Not to be ambiguous in any matter of importance, we must say that, unless the new fuel, either oil or gas, is used with more knowledge, care, and consideration than that bestowed on solid fuel, no saving of money or time will follow, while an element of danger is always present.

Clearly no reckless introduction of natural or other gas fires should be encouraged in the dwelling, the schoolhouse, or the church; and all appliances for the control, regulation, and safety of liquid and gaseous fuel should be required by law, and passed upon by a board of competent engineers, as is now done with other dangerous explosive agents. Steam should be brought under the same official scrutiny.

As natural gas is so largely composed of marsh gas, it forms, when mixed with air, an explosive compound similar to the deadly fire damp of the coal mines. Consequently, fire must be applied to the orifice before the gas is turned on, or else there will be an explosion. To avoid such a possibility, a small jet of gas is often allowed to burn all the time, in order to light the large burner as soon as gas is turned on.

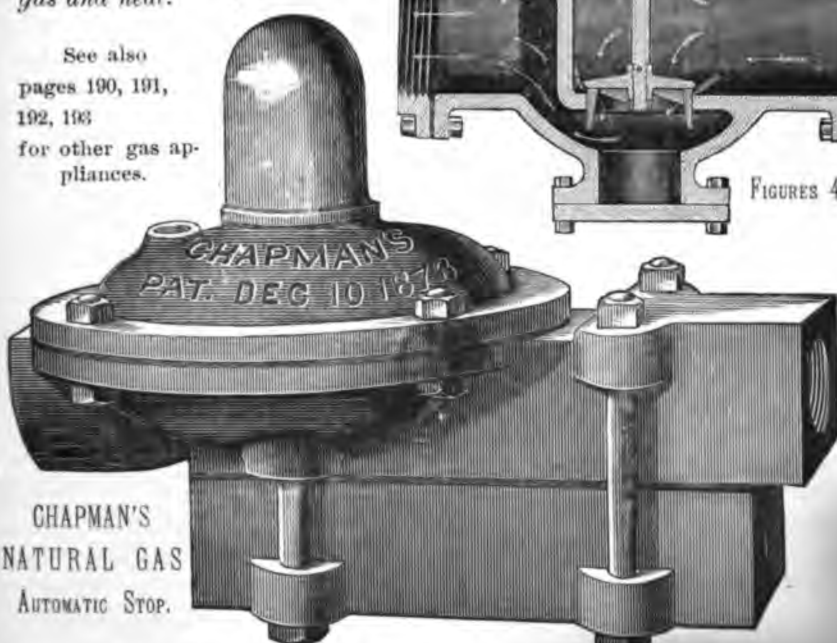
If restriction to simply guard a fire risk is necessary with a comparatively safe fuel, as crude or refined oil, evidently some safeguards should be thrown around a fuel as combustible and explosive as gunpowder, and all possible precautions against accidents by the use of automatic devices should be insisted upon and carefully and intelligently applied.

Such devices have been invented, and largely introduced in and around Pittsburg. They consist of the safety valve, the reducing pressure valve, and the automatic shut-off, to cover the danger of a return of the gas, as, after it has been shut off for any reason, *this valve closes, and will not again open until the engineer is ready for gas and heat.*



FIGURES 4 AND 5.

See also pages 190, 191, 192, 193 for other gas appliances.



CHAPMAN'S NATURAL GAS AUTOMATIC STOP.

Atwood & McCaffrey, Manufacturers, Pittsburg, Pa.

BURNING CARBONIC OXIDE GAS AT FRANKLIN, N. Y.

In the year 1875 and 1876 the writer was called to the above town (near Utica) to examine the furnaces, boilers, and plant employed in the manufacture of pig iron, there being a bed of natural ores at moderate depth, which, mixed with Lake Superior ores, produced a soft and rather superior iron.

The Directors at the time were Mr. Delos DeWoolf, of Oswego, Mr. Armstrong, of Rome, with C. H. Smythe, General Superintendent.

The matter to be discussed was *boilers*, their method of producing their power, and heating the air for the blast. The question of fuel was an important one. Wood and coal were dear, coming from long distances, and the labor of handling them was excessive.

They had, therefore, with many others in the pig-iron business, begun to utilize the waste gases escaping from the cupola, where the closed method renders the recovery of these gases possible.

This is readily understood by furnace men; but it may be explained to consist of a "Bell" cover or hood, that, after charging the coal and iron ore, was lowered over the top of the stack, thus retaining the gases in the cupola under pressure, and enabling the recovery and control of these gases for use under the boiler and ovens, as before stated.

It was, however, more or less a dangerous operation, and sometimes attended with the most disastrous results, since a gas of this nature and at the temperature of say 800° to 1,000°, when mixed with certain quantities of air, becomes an explosive as powerful as gunpowder or gun cotton.

To return to the conditions under which the gas was taken to the battery of boilers for the generation of steam. The gas was brought down from the top of the cupolas in a pipe three feet in diameter, about one thousand square inches area of section, and, at the velocity due to the pressure and the draught of a high chimney, supplied fuel enough, when mixed with air, to yield one thousand horse-power.

The boiler then in use was the older plain cylinder boiler, without tubes or flues, the shells being very long (some fifty feet), the products of combustion then passing to the chimney.

The water of this section contained much organic impurity, to which were added the oils carried over in the exhaust steam of the blowing engine, forming a compound on the lower shells of the cylinder boiler that caused them to blister and bag down under the excessive heat of the gas fire, carrying a flame the whole length. Thus stoppages to clean out the sediment were frequent, with the danger of explosion always present, and only averted by constant care and watchfulness on the part of the engineers and firemen.

The immediate result of this visit and report was a contract to supply the works with two hundred horse-power of the writer's sectional cast-iron boilers.* These were the whole section pattern No. 3 for power, and were erected in single line one hundred sections, making a boiler fifty feet long. The steam and water drums were flanged and bolted together, substantially as those in sectional elevation, shown herewith. This was the patent of 1871, and referred to in the report of E. H. Hewins, G. B. N. Tower, and others. See table No. 7, p. 265.

The steam pressure carried was sixty pounds, and the work was the hardest possible, being continuous day and night, under the intense gas flame noted. The use of these cast-iron boiler sections was continued about a year, when the Directors ordered a second series, saying that "*the steam pressure had been more constant, and, notwithstanding some breakages due to low water, that the repairs had been far less numerous and expensive than for the same time using the wrought-iron boilers.*"

It may be remarked that the effect of low water, with undue expansion in these boiler sections, is to cause a *crack*, *instead of a rupture*, and that sections so cracked were continued in use until a convenient time for their removal. This has been the case in low-pressure heating; a cracked section has also closed up, and was not removed until the heat could be dispensed with.

The application of the gas to the heating surfaces of the sectional boiler at Franklin was not *en masse* as formerly, but taken into large burners or mixers, on the "Argand" principle. The pipes forming the outside shells were twelve inches in diameter and nine feet long, and had an opening every six inches; these were four inches in diameter, through which the three-inch air nozzle entered, thus leaving a one-half inch annular space for the gas, and the three-inch pipe in the centre for the air, the relative areas thus being four square inches gas to seven air. This is a greater proportion of air than is called for in the Table of Combustibles, No. 3, page 36 (which in practice is found too little), but it is much less than would be required for any of the other gases. Combustion in our case was found to be very perfect, the air, as seen, being preheated to a high temperature by the surrounding gas (itself at some 700° or 800° Fahr.); but little smoke was made, a clear, bright flame resulting, and the temperature was high, even after the products of combustion had passed the boiler, and entered the chimney.

NOTE. — A section at the dwelling of W. H. Walker, Esq., Delaware Avenue, Buffalo, N. Y., was cracked in the winter from having the water cut off in the street without notice; the crack showed plainly, leaked a little for a few days, and then closed up and was used through the winter.

* For cut of this boiler, see pages 268, 287,

CONDITIONS FOR COMPLETE COMBUSTION OF GAS AND OIL.

If great difficulty has been found in burning the solid fuels, with which engineers and firemen have been familiar for a hundred years, what may be said or expected of the use and application of fuels which have been available but a few years, and in which the combustibles are in entirely different combinations? While our common illuminating gas has offered serious obstacles to any extended application for heating purposes, the Bunsen burner and later constructions on the same principle showed conclusively that air or the oxygen that it carried was the controlling agency and key to all economy in its use for purposes of heat.

This has also been true of its use for light, and the finest lamps now both *preheat the gases and the air*, and combine them prior to combustion in the burner.

Perhaps no other condition is so essential as a high temperature to the perfect combustion of all fuels. Certainly this is true of the petroleum and natural gases on the large scale. As for heating and puddling iron, not so much difficulty is found, owing to the magnitude of the operations and the amount of fuel in combustion; but, in smaller operations, as in fires under domestic boilers and heating apparatus, much difficulty is experienced and many failures recorded. Indeed, some of the worst ever known occurred in this line, first, from a total ignorance of the ingredients to be treated; and second, from adverse conditions in the fire chamber itself. The adverse condition we refer to in domestic heaters is the large amount of cooling and condensing surface surrounding the fire chamber. The side, top, and bottom of such heaters are generally the wall and tubes filled with water, from which steam is raised, or the water itself used as the heating medium. The last, the water-circulating boiler, presents the most difficult conditions for the novice to understand, since the essential to combustion, *high temperature*, is more lacking here than in steam boilers or, indeed, in any other furnace.

The points which operators have missed are, first, a proper mixture of the gas to be burned with the required air; and, second, a mixture of them in the furnace prior to combustion, and protected meanwhile from the effects of the surrounding body of water; third, a failure to shut off all air from the fire chamber other than that provided for at the burner. Even if successful in the other essentials, if air be admitted uncombined with the gas, the temperature would be low at first, and lower as the products of the imperfect mixture flowed in among the tubes, and even condensation would ensue, defeating the whole operation; while the product of this incomplete combustion—

call it distillation, rather—is destructive to life and even the brick wall of the furnace and chimneys with which the heater was connected. An operator at Titusville, writing of this matter under date of Jan. 11, 1886 (*Sanitary Engineer*), says: "The doors about the furnace should all be *closed tight*. If they will not do this, they should be refitted and made to, as no air should enter except that drawn in with the gas through the injector." After directing that the gas and air should be delivered some three or four inches above the grates, he says: "Then fill the fire pot with broken fire brick about as it should be filled with coal (that is, about seven or eight inches deep); put in a lighted taper or torch, and turn on the gas."

The one hundred or more pounds of fire brick above, where the gas is delivered, is to ***protect it from cooling influences until the process of admixture and combustion is complete.***

In applying the gas furnace to internally fired boilers, it was foreseen by M. Fichtet, after his experience with the ordinary French boiler, that special precautions must be taken to provide against the premature cooling of the gases and the extinction of the flame. In the arrangement which he employed the temperature of combustion is maintained by a fire-brick lining, so that the combustion is completed before the flame can touch the sides of the surface of the metal. It is sometimes found of advantage to raise a perforated fire-brick wall or diaphragm at the inner end of the fire-brick chamber, substituting, at the same time, two long vertical sheets of air through the door for the multi-tubular jets. The products of combustion, after circulating around the boiler, pass through the chimney.

Many varieties of gas furnace have been employed for heating steam boilers, and many have been forgotten.

M. Fichtet, when he applied gas furnaces to steam boilers, under arrangements similar to those which had given so satisfactory results when employed for the manufacture of coal gas, naturally expected similar success. But he was disappointed.

By the rapid cooling of the flame in contact with the surface of the boilers, he was led to the production of generators very differently arranged, for the service of steam boilers. When he used dry combustibles, and admitted a quantity of air very little in excess of the quantity required for chemical combustion, the flame was extinguished when it came in contact with the boiler; and the products of combustion proved, on being analyzed, to consist of a mixture of free oxygen and carbonic oxide with nitrogen and carbonic acid.

Natural gas was introduced into Buffalo the last year that the writer was there permanently, 1886 and 1887, and he watched with interest such applications as came within his reach, principally to dwelling-houses and their heating apparatus and to some boilers for power purposes.

In the first, where the gas was connected with the cooking stove, range, and grate, and using a common atmospheric burner, but little trouble was experienced and much comfort was derived.

In the second, the application of gas to heating apparatus, there seems much greater difficulty, little or no economy, sometimes a waste and a positive loss, and at others disaster and explosion.

Indeed, how could it be otherwise? Into whose hands has the introduction of natural gas fallen? Generally into those of the steam fitters—the men who cut and hang up the pipes that convey the steam or water around the building.

Is there any material connection between these men, brought up to the crudest kinds of mechanical labor, and the beautiful science of chemistry? About as much as there is between a coal heaver and the electric light. They could as soon make a proper installation in one case as the other; and yet, because these men can cut off and screw together the iron pipes in which the gas is brought to the building, they assume and are credited with a knowledge they have had no means of acquiring.

Nowhere is this seen so clearly as in their crude application of natural gas to steam and water boilers for house heating.

Generally these are of the internal furnace variety, where the fire chamber is entirely surrounded with water, and where, from the very nature of the work to be done, the temperatures of all the absorbing surfaces are low. To thrust an ordinary burner through the fire door and turn on the gas, is to invite failure from the start, *as a certain and determined prior mixture of the air and gas and high temperature are essential to complete combustion.*

This prior mixture, high temperature, and perfect combination must be secured *before* the gases are turned loose in and among the comparatively colder surfaces of the boiler; otherwise, the half mixed and burned gases are drawn in among the tubes, are *condensed*, and in that imperfect state pass away in the chimney or fall to regions of still lower temperature, emitting the most noxious odors and even endangering the safety of the apparatus, the dwelling, and its inmates.

Of the several different attempts to burn and utilize natural gas in the boilers of the writer, all were failures; not as the parties operating suppose, because these special boilers had any particular objection to being heated with gas instead of coal, but because the main and essential

conditions of success were neglected. The better the boiler as a rapid absorber of heat, the harder would be the task of securing in and around the burner the proper mixture and high temperature absolutely required.

This is why that, under the regular tubular boiler having a brick furnace and no near absorbing water surfaces, and requiring no throttling of the gas, little trouble has been experienced; and, barring the economy missed, there *should be* no real difficulty in such cases.

The greatest success in burning natural gas seems to have been reached at McKeesport, Pa. (described on page 179), where the gas itself is preheated to nearly 3,000° prior to the mixture with the air, and under this simple change from cold gas and cold air an economy of nearly 88 per cent was secured, with a corresponding greater rapidity of work accomplished.

This example furnishes the real key to more practical work with natural gas, or, indeed, with any other gas fire; it also points directly to the reason of the constant failures attending all attempts at burning natural gas in heaters or boilers, having a large condensing or cooling surface immediately around the point where combustion is sought to be effected.

The same conditions of high temperature and proper mixture of the air are required when oil is the fuel, and the writer believes that the best results have rarely been reached with this fuel.

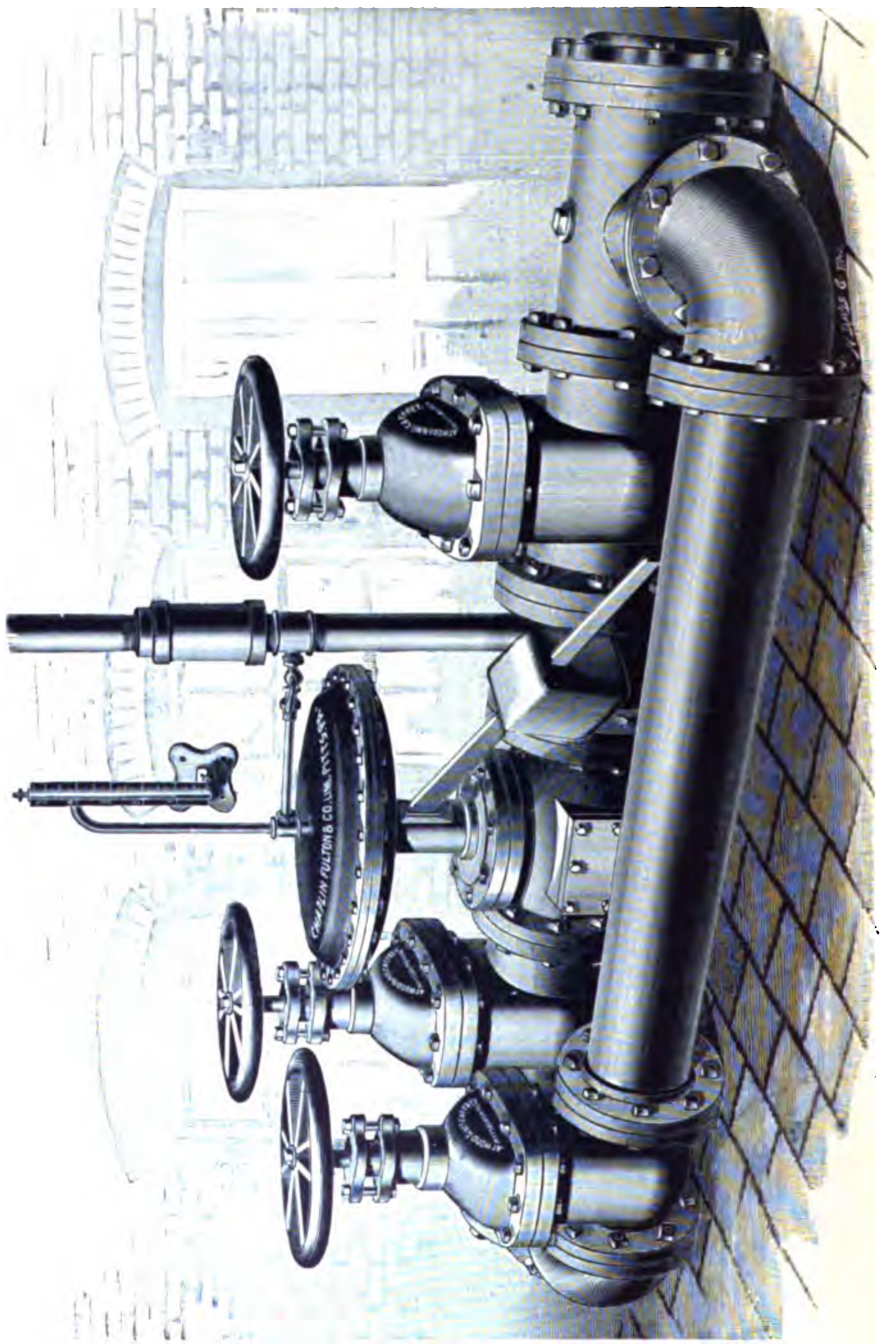
Thus we see that the theoretical heat value of hard coal is (page 144) 13,525 British thermal units; of soft coal, 15,465, and of crude oil 21,192 units per pound of fuel, and the money value of these three kinds of fuel is substantially equal, with coal at $4.50 per ton and crude oil at 3 cents per gallon. We also see (page 145) that the steam-producing power of petroleum is 22.08 pounds of water, evaporated from and at 212° per pound of oil; but by the actual tests made (table No. 5½, page 158) only 15.54 pounds were evaporated, or 75 per cent of that theoretically possible; while coal under the same conditions utilizes 67 per cent of its theoretical evaporative power.

This, while doubtless a better result than is ordinarily obtained with any of the steam jet or spray burners, is still below the best possible results, and can doubtless be traced to some or all of the adverse conditions noted in burning natural gas.

The writer has seen many times the arrangements noted on page 158, and observed that there was little or no differences in the treatment of the two fuels; that is, the air was allowed to enter the ash pit in the case of oil as when using coal, with the intention, of course, of aiding combustion; the result, I am confident, was the cooling of the gases at the critical moment and a loss of efficiency.

PLATE No. 5.

*REGULATOR AND BY-PASS FOR NATURAL GAS.



* **Atwood & McCaffrey, Manufacturers, Pittsburg, Pa.**

APPLIANCES FOR BURNING GAS.

An arrangement for burning the gas under the boilers is practiced by the Electric Light Company at their central station in Pittsburg, Pa. The gas passes into a four-inch drum extending in front of the boilers, and thence by a one and a half inch pipe into T burners in the front of the fire box. These are simply perforated pipe, 2″ in diameter.

The air for combustion is first heated before mixing with the gas. Sheet-iron is placed upon the grate bars to within about four inches of the rear, and two-inch tiles are placed between this and the boiler, leaving sufficient space in front for the flame to play over them. The air enters beneath, and, passing along the under side of the tiles, is heated before coming in contact with the gas. It is very important at such an establishment to be able to burn coal at very short notice, should any accident happen to the gas supply. As at present arranged, the entire change can be made and a coal fire started within eight minutes. The gas is burned under the boilers at a pressure of from three fourths to one pound. As the pressure in the mains is considerably in excess of this, it must be reduced by means of an automatic regulator. In dwelling-houses the gas is seldom burned under more than two to six ounces.

FIGURE No. 6.

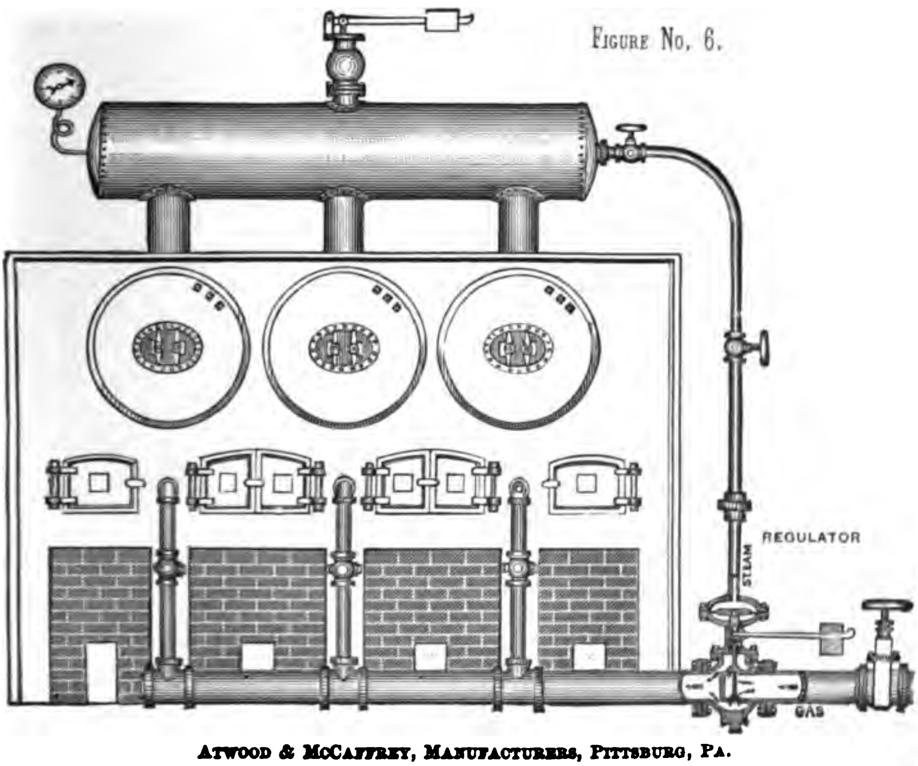
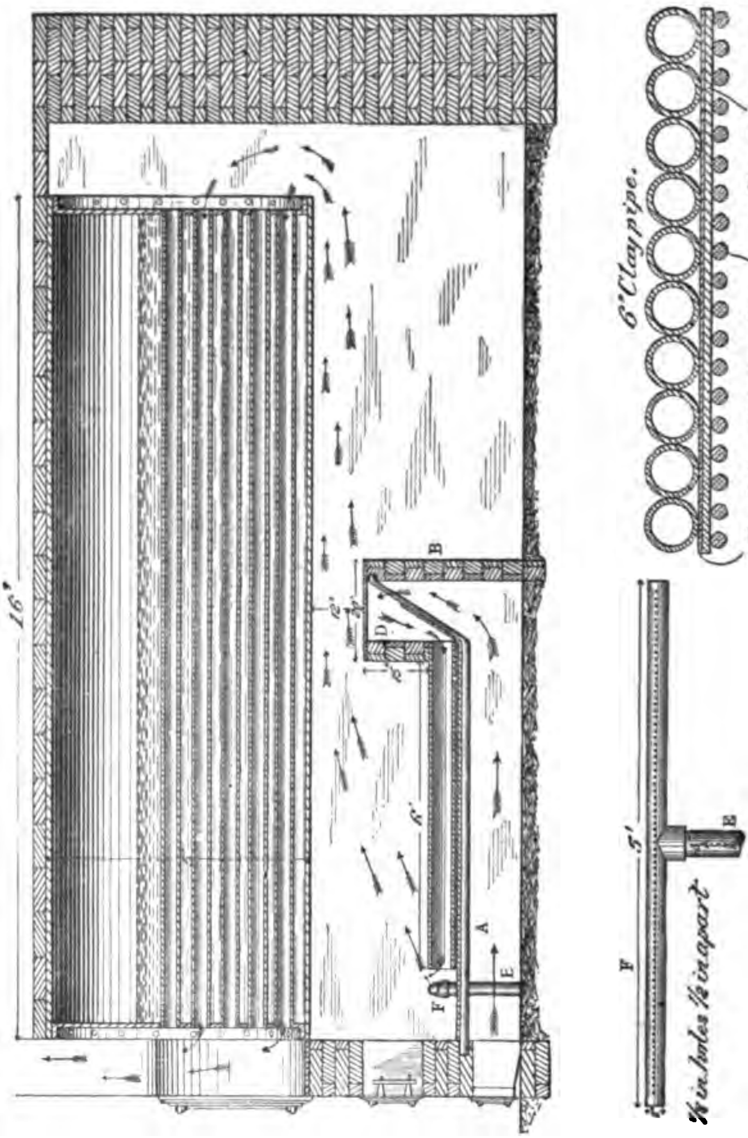


PLATE NO. 6.

Arrangement for Burning Natural Gas under Boilers.

The air to combine with the gas enters through the ashpit A and bridge D, and through the ten 6-inch clay pipes, meeting the gas at the burner F. The ashpit is made tight over the bars, so that *no air enters uncombined with the gas.*

(See also figure No. 7, with burners for gas and oil fuel.)



Hot air to meet the gas at F.

Gas supply through pipe E to meet the air at F, as shown.

RECAPITULATION.

Natural gas has been in use from remote periods for industrial purposes.

Its occurrence was observed in America by the earliest settlers, in burning springs — (*also in the burning bush by Moses.*)

It has been used for lighting in the United States since 1821.

The date of the first *extended* application of natural gas as a fuel for heating and a source of power was about 1884.

Since that time gas has been discovered in commercial quantities over a large region in Pennsylvania, New York, Virginia, Indiana, Illinois, and Ohio, in general the same as that in which petroleum oil is found.

The constituents of natural gas are chiefly marsh gas or light carburetted hydrogen and in some localities hydrogen.

Its calorific value is not exceeded by any other substance available for fuel, liquid, gaseous, or solid.

One pound of natural gas (26.2 cubic feet) of average composition has total heating capacity of twenty-two thousand thermal units, or is the equivalent of one and three-quarter pounds of coal.

In the best practice one pound of the gas, or about twenty-six cubic feet, is equivalent to two pounds of good coal.

The inventions and appliances for distributing and burning natural gas, and the experience of its advantages as a fuel over solid substances, are leading the way to the general use of gaseous fuel for heating purposes and for power.

The burner shown is that often employed in the gas regions and elsewhere when using natural gas under boilers and furnaces, a diaphragm being used (not shown) to control the pressure and the amount of gas burned. There is also a valve in the 3-4-inch gas pipe not shown.

The air enters at the end of the burner or mixer, and makes in reality a large "argand" burner. The amount of air entering should be controlled at the perforated cap (see arrows). *But all other air should be excluded by a tight front and a closed ash pit,* the grate bars being covered over, and fire brick or clinker should then be placed on the grate through which the gas and air should pass.

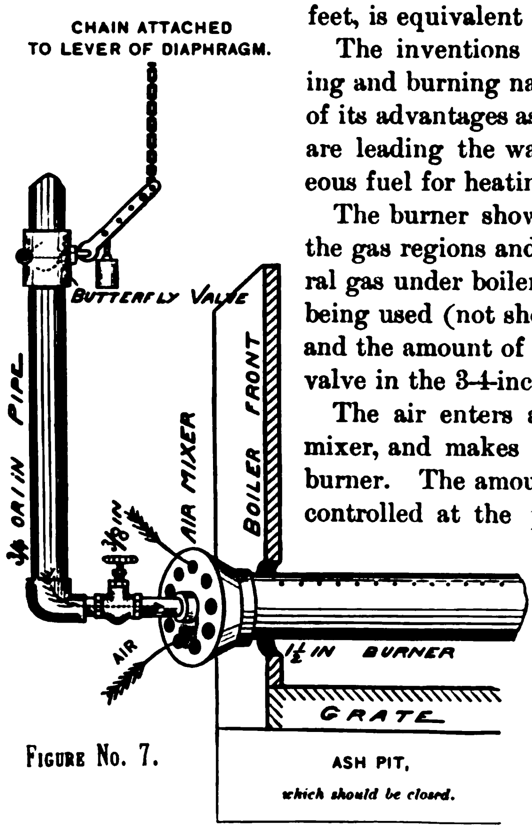
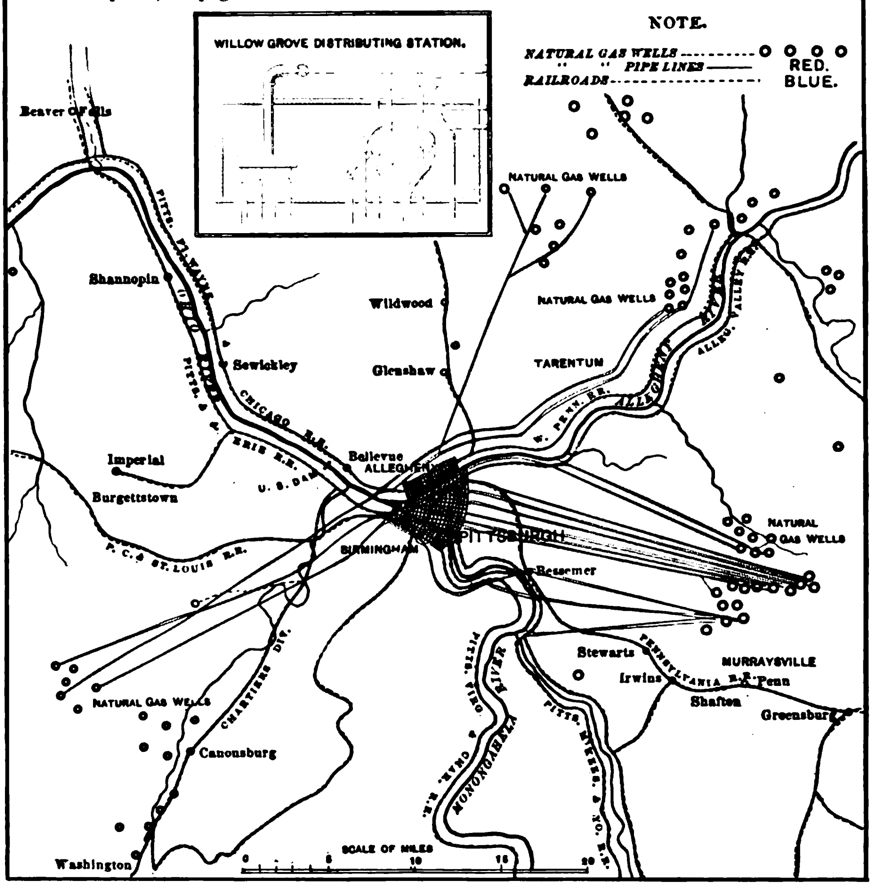


FIGURE No. 7.

DIAGRAM No. 13.

PIPE LINES FROM NATURAL GAS REGIONS TO PITTSBURGH, PA.

For description, see page 173.



From the most reliable data obtainable, it appears that the total amount of pipe thus far laid around Pittsburgh is about 600 miles, of which the Philadelphia Company owns 340 miles, the remainder being distributed among the others. The pipes are from 6 to 24 inches in diameter. Within the city the Philadelphia Company has about 80 miles of mains laid, and has about 800 men constantly employed. The pipes from the wells range from 10 to 16 inches, wrought iron, while those within the city are 20 to 24-inch mains, with a system of radiating 6, 8, 10, and 12-inch service pipes. The present supply of the city is from 50 wells, of which the Philadelphia Company owns 34; but there is a very large number drilled near the gas producing sand, ready to be brought in whenever there is any occasion for their use.

"It is only fifteen years ago," says the editor of *Stoves and Hardware*, published at St. Louis, "that natural gas was first used as a fuel; yet to-day there is required to pipe it 7,350 miles of mains. In Pittsburgh alone 500 miles supply 42,698 private houses, 40 iron mills, 37 glass works, 83 foundries and machine shops, and 422 miscellaneous manufacturing establishments.

"An idea of its importance as fuel can be obtained when the value of 7,000,000 *tons of coal is estimated. It is asserted that this amount of coal is annually displaced by natural gas; say* $20,000,000, *not estimating the* OIL *now used as fuel.*

CHAPTER XIII

MANUFACTURED AND CARBURETTED GAS.

AN abstract of a paper in the *Journal of the Society of Chemical Industry* states: "There are three kinds of gas made for heating purposes; viz. *illuminating*, *generator*, *and water gas.*

Illuminating gas is obtained by distilling coal and decomposing the volatile products into combustible gases. Generator gas is produced from gas generators fed with coke, by burning the solid carbon to gaseous carbonic oxide. Water gas is made by the combustion of red-hot coal in steam. In the manufacture of illuminating and water gas heat is required and consequently absorbed. Generator gas, on the other hand, is formed with evolution of heat, and the amount of heat given off in the process is not only sufficient to maintain its action, but part escapes into the gases evolved. See table No. 3, page 36.

"Illuminating gas possesses advantages where it is a question of bringing gas a great distance from a central gas works, for it is evident that a system of pipes of given dimensions can convey about twice as much heating power with illuminating as with water gas. *Per contra*, the constituents which impart the illuminating power are expensive, while entirely unnecessary for fuel purposes. And yet, high priced as it is, practical experience in its use proves that in some departments, at least, it is certainly cheaper than coal, besides its collateral advantages; and it is at the present time employed to a limited extent by those who have become familiar with the facts. Exceedingly interesting tests have been made by the London engineers with the city gas, developing some economic features quite surprising; and at the meeting of the American Gaslight Association, in 1887, a paper was presented by one of the members showing that careful experiment had so demonstrated the saving, even at $3 per thousand feet, that nine tenths of his customers were using it in preference to wood or coal for kitchen and laundry purposes."

* **Difficulties Attending the Use of a Crude Form of Fuel.** To illustrate, let us take the most familiar methods, such as are employed in domestic cooking and heating.

Ignoring the mechanical imperfections of stoves and furnaces, lest an examination of them should extend this article unduly, we will examine the more evident sources of loss: —

The expenditure of fuel in generating heat at times when it is not utilized. Every housekeeper must have been struck with the fact that a large amount of wood and coal is burned before the range is ready to cook, and that a probably larger amount still is used after the cooking is done. Annoying as this may be, it is cheaper to keep the fire up between meals, even in summer time when it is undesirable, than to let it go out and rekindle three times.

The excessive quantity employed while in use. Often to accomplish some trifling result, like the boiling of a tea-kettle, the whole area of fire space is unnecessarily kindled, although not one tenth of it is required. Twenty pounds of good anthracite coal contains heat enough to raise two hundred and seventy thousand pounds of water 1° in temperature, or seventeen hundred and seventy-six pounds from 60° Fahr. to the boiling point, 212° Fahr., and yet it is to be feared that this power is frequently employed in cooking a pot of coffee.

If we have expended for our morning draught heat enough, if perfectly applied, to raise three fourths of a ton of the same liquid from atmospheric temperature to the boiling point, it may be considered a somewhat luxurious beverage.

The items of labor and inconvenience incident to the use of coal are too apparent to need any enlargement.

These are the principal arguments against the general use of fuel in its natural condition, and they appear formidable enough to justify the assertion that not over 10 per cent of the heating power of such fuel is utilized in the best of our coal stoves and ranges.

Let it be remembered that it is, in all cases, largely gas that we burn, and from which we derive heat; so that the question is, whether each family can make a limited quantity of the gas as economically in defective ranges and stoves, as the same or a much better article can be manufactured on a much larger scale at some great establishment, whence it could be distributed to customers. There can be no doubt that the advantage possessed by all concentrated industries exists in this one, at least to as great a degree as in any other department of manufacture. We might as reasonably expect to grind our own flour, or weave our own fabrics economically, as to successfully compete with gas works properly constructed and skillfully managed.

* Barr: "The Combustion of Coal."

To those who have given the subject any thought, therefore, the designations "wasteful, troublesome, and dirty" are not too strong in characterizing the use of coal in the family.

Students and inventors have long since appreciated the lamentable deficiencies of the present method of supplying heat for the household, and have suggested several plans for reform. These plans, some of which have had measurable success in practice, all proceed upon the principle of supplying the heat from some central source of supply. The methods proposed involve the use of either steam, superheated water, or fuel gas. In all these plans the heating agent is supposed to be generated at some centrally located station, from which it is to be distributed by suitably protected pipes through the streets and into the houses where it is to be consumed.

Unquestionably the plan of the future consists in the production of gaseous fuel at central stations, and its distribution to and through our houses.

The possibilities of fuel gas made a profound impression upon observing and practical men some years ago, when it was demonstrated that water gas produced by the mutual interaction of steam and carbon at high temperatures could be made in immense volumes at a very trifling cost. The resulting gaseous product of this reaction, consisting substantially of hydrogen and carbonic oxide, furnishes a fuel as nearly perfect as could be imagined.

Both ingredients are highly combustible, yielding an intense heating effect when ignited, and the products of combustion are gaseous.

By the adoption of gas in our houses for cooking and warming, the existing contrivances can be utilized with but little alteration, and as much or as little heat as may be required can be turned on at pleasure. When not needed, the fire may be extinguished by the simple turning of a stop cock. It gives complete exemption from the trouble, dirt, and wastefulness of coal. Our fires will not need to be kept up over night summer and winter, as they now are because of the trouble of making them up fresh in the morning. The gas fire can be made in an instant, and extinguished as quickly when it has served its purpose, and its heating effect can be controlled to a nicety for hours at a time. By the admission to the product at stations of a trifling percentage of naphtha or some one of the petroleum products, to give a sensible and penetrating odor like coal gas, so that its leakage may be at once detected by the smell, it will be as safe and completely under control.

It is a subject of surprise to us, in view of the perfect adaptability of fuel gas to domestic purposes, that it has not already found its way into general use.

TABLE OF COMPARISON BETWEEN COST OF COOKING BY COAL AND GAS.

TABLE No. 6.

*RECORD OF PEERLESS COAL RANGE, NO. 8.

ARTICLE.	How Cooked.	Weight. Before Cooking.	Weight. After Cooking.	Loss per cent.	Time.
Bluefish	Baked.	3 lbs.	2 lbs. 1 oz.	32	31 m.
Rib of Beef . . .	Roasted.	9 lbs. 7 oz.	6 lbs. 8 oz.	32	1 h. 37 m.
Chicken	Roasted.	3 lbs.	2 lbs. 2 oz.	30	1 h. 6 m.
Beef Steak . . .	Broiled.	1 lb. 2 oz.	13½ oz.	25	11 m.
Lamb Chops. . .	Broiled.	1 lb. 1 oz.	11 oz.	35	12 m.
Sweet Potatoes. .	Steamed.	3 lbs. 5 oz.			
White Potatoes. .	Steamed.	3 lbs. 8 oz.			
Cauliflower . . .	Boiled.	3 lbs. 12 oz.			
Tomatoes. . . .	Stewed.	4 lbs.			
Bread	Baked.		5 lbs. 2 oz.		40 m.
Sago Pudding . .	Baked.		3 lbs. 5 oz.		27 m.
Lemon Pie . . .	Baked.		2 lbs. 12 oz.		30 m.

Total time from lighting of fire until everything was ready to serve, 2 hours and 40 minutes. Of this time, 30 minutes were required to heat the oven, leaving 2 hours and 10 minutes actual cooking time. Weight of coal, including lighting of fire, 44 lbs. At the end of the time, the fire was ready for more coal. Cost of coal, 44 lbs., at $5.50 per ton, 10.95 cents. Kindling, 1 cent. Total, 11.95 cents.

RECORD OF NO. 7, "SUN DIAL" GAS STOVE.

ARTICLE.	How Cooked.	Weight. Before Cooking.	Weight. After Cooking.	Loss per cent.	Time.
Bluefish	Baked.	3 lbs.	2 lbs. 6 oz.	20	35 m.
Rib of Beef . . .	Roasted.	9 lbs. 4 oz.	7 lbs. 11 oz.	17	1 h. 25 m.
Chicken	Roasted.	3 lbs. 1 oz.	2 lbs. 10 oz.	14	1 h.
Beef Steak . . .	Broiled.	1 lb. 2 oz.	15 oz.	16⅔	8 m.
Lamb Chops. . .	Broiled.	1 lb.	13½ oz.	15	10 m.
Sweet Potatoes. .	Steamed.	3 lbs. 5 oz.			
White Potatoes. .	Steamed.	3 lbs. 8 oz.			
Cauliflower . . .	Stewed.	4 lbs.			
Tomatoes. . . .	Boiled.	3 lbs. 12 oz.			
Bread	Baked.		5 lbs. 7 oz.		37 m.
Sago Pudding . .	Baked.		3 lbs. 3 oz.		28 m.
Lemon Pie . . .	Baked.		2 lbs. 14 oz.		22 m.

Total time from lighting of gas until everything was ready to serve, 1 hour and 50 minutes. Consumption of gas by test meter, 38 feet. At $2.15 per thousand feet, cost 8.17 cents.

Cost of Coal	**11.95 cents.**
" Gas	**8.17 "**
Saving over Coal	**3.78 cents = 32 per cent.**

*Goodwin Gas Stove and Meter Co., 1012 Filbert St., Philadelphia, Pa.

TABLE No. 6½.

*PRICE OF GAS AND THE ELECTRIC LIGHT IN THE PRINCIPAL CITIES OF THE COUNTRY.

In view of the present gas agitation, the following table will be of interest. It gives the price of gas in the principal cities of the United States. The figures represent the price per thousand feet charged to private consumers during the summer of 1884. Many companies have adopted a sliding scale, by which large companies receive certain reductions not granted to the consumer of a few thousand feet per month; the object here, however, has been to give the price charged to the latter class. The average candle-power is also given in most cases. The gas table was compiled by Dr. E. G. Love, Gas Examiner of N. Y.

LOCATION.	Pr. per M.	Candle Pr.	LOCATION.	Pr. per M.	Candle Pr.
Albany, N. Y.,	$2.50	18–19	Denver, Col.,	1.75	20
Allegheny, Pa.,	1.25	15	Newark, N. J.,	2.00	19–20
Atlanta, Ga.,	1.50	17	New Bedford, Mass.,	1.87	18
Auburn, N. Y.,	2.25	19	New Haven, Conn.,	2.00	16–17
Augusta, Ga.,	2.50	—	New Orleans, La.,	3.50	—
Baltimore, Md.,	1.00	20	Newport, R. I.,	2.00	18
Bay City, Mich.,	2.25	—	New York, N. Y.,	1.75	18–30
Boston, Mass.,	1.50	19	Norfolk, Va.,	1.80	20
Brooklyn, N. Y.,	2.00	—	North Adams, Mass.,	2.37	—
	2.25	—	Omaha, Neb.,	2.50	16
Buffalo, N. Y.,	1.80	20	Oswego, N. Y.,	2.25	—
Cambridge, Mass.,	2.00	17	Peoria, Ill.,	2.00	16
Camden, N. J.,	1.50	17	Petersburg, Va.,	2.50	17
Charleston, S. C.,	2.50	—	Philadelphia, Pa.,	1.70	16–17
Chelsea, Mass.,	2.50	18	Pittsburg, Pa.,	1.00	—
Chicago, Ill.,	1.00	—	Pittsfield, Mass.,	2.40	—
	1.25	—	Portland, Me.,	2.00	17–18
Cincinnati, O.,	1.60	16	Poughkeepsie, N. Y.,	2.14	18
Cleveland, O.,	1.40	—	Providence, R. I.,	1.80	17–18
Columbus, O.,	1.25	17	Quincy, Ill.,	2.25	16
Covington, Ky.,	2.00	17	Reading, Pa.,	2.00	24
Davenport, Ia.,	2.50	16	Richmond, Va.,	2.00	17–18
Dayton, O.,	2.00	16	Rochester, N. Y.,	2.00	—

It appears that in the United States there are upwards of 95,000 arc lamps and 250,000 incandescent lamps, distributed over 400 towns and cities. Only 13 years ago Professor Tyndall exhibited in Philadelphia probably the first arc light seen in public in the United States, and at present there are not less than $70,000,000 invested in the business of electric lighting in this country alone; at least 25,000 incandescent and 12,000 arc lamps are newly installed each year. Over 6 tons of mercury and 700 air pumps are in use for the manufacture of glow lamps. In Paris in 1878 the cost to the city was at the rate of 29 cents per hour for a lamp of from 500 to 700 candle-power. To-day, under like conditions, the city of New York pays at the rate of about 6 cents per hour for a lamp of 2,000 can[illegible]er. There are 300,000 carbons manufactured for arc lamps in t[illegible]ed States daily, one of our largest firms consuming twen[illegible]f petroleum coke per week.

* *Sanitary Engineer and Building Record.*

Heat Utilized in Furnaces. Professor Gruner, in the *Engineering and Mining Journal*, states that "In the *wind furnace*, which is from this point of view the most imperfect apparatus, there is utilized in the fusion of steel in crucibles but 1.7 of the total heat capacity of the fuel, or, at the most, 3 per cent of the heat generated. In the *reverberatory*, when steel is melted in crucibles, the useful effect is 2 per cent of the total heat, or 3 per cent of the heat generated. In the Siemens crucible furnaces, 3 to 3.5 per cent; in Siemens glass furnaces, operating on a large scale, 5.5 to 6 per cent; in ordinary glass furnaces, 3 per cent; in fusion upon the open hearth or a reverberatory, of glass, 7 per cent; of iron, 8 per cent.

"In well-arranged *Siemens and Ponsard* furnaces, up to 15, 18, and even 20 per cent of the total heat is utilized. The calorific effect is much greater when the fuel is mixed with the material to be fused.

"Large *iron blast-furnaces* utilize, according to the working, 70 to 80 per cent of the heat generated, or 34 to 36 per cent of the total heat which the complete combustion of the fuel would set free.

We are thus furnished with a basis of comparison between the efficiency in actual practice of crude coal and water gas; for it is estimated that, by reason of its instant mixture with the oxygen of the air, the combustion of the gas is so perfect that the heat generated would be 90 per cent of the full theoretic power by any rational system which would use the available heat in the products of combustion.

Another cause of loss in the burning of crude fuels, and one of sufficient importance to deserve mention, is the fact that there is mixed with the carbon a considerable quantity of foreign matter not combustible, which absorbs heat and gives no equivalent. This is represented principally by the ash and the clinker, which every consumer of coal knows to be a large item. It reaches from 10 to 15 per cent of the material.

Therefore, while 2,240 pounds of coal represent a total theoretic value of 29,120,000 heat units, the value really utilized by the best modern blast furnace, according to Professor Gruner (36 per cent), would be 9,483,200.

The weight of gas which the same ton would produce, viz., 2,050 pounds, possesses a total value of 18,035,900 heat units, of which 16,232,310 are actually available in practice, showing an advantage of the new fuel against the old as 1.71 is to 1. This advantage, moreover, exists upon the basis of a similar price for the coal employed in the two cases; while, in fact, there is a still further gain in favor of gas, owing to the fact that it makes available a much cheaper material (slack) than can be employed in the direct furnace operation, a difference at tide-water of about 2.5 to 1."

ILLUMINATING AND HEATING CONSTITUENTS OF COMMON GAS.

Dr. Charles William Siemens, of Westminster, Eng., the distinguished inventor of the regenerative gas furnace, the Siemens direct and open hearth steel processes, and the Siemens-Halske dynamo-electric machine, has recently called attention to some new discoveries in the manufacture and utilization of illuminating gas, which appear to be of great importance.

To gas manufacturers he points out that the gas coming from a retort varies very greatly in its character during progressive periods of the charge; that, during the first quarter of an hour after closing the retort, marsh gas, of little use for illuminating purposes, is formed; then for a period of two hours rich hydrocarbons are given off, and afterwards marsh gas again. If the first and last results of the distillation are led into a main, separate from that into which the intermediate results are conducted, two thirds of the volume of all the gas produced will be rich illuminating gas, while the remaining one third will be weak gas available for heating purposes. The illuminating gas, moreover, will have a higher candle power than when mixed with the marsh gas; while the latter, being less liable to deposit soot, will have a higher calorific power than the former.

The mechanical contrivances for effecting this separation are simply a reversing valve to change the direction of the gas outflow, and, of course, a double set of mains — one set for the illuminating and the other for the heating gas.

LOSS IN THE BURNING OF SOLID FUEL.

There is always a loss attending the generation of heat from carbonaceous fuels, and perhaps as much more heat is lost in its application to any economic use. The loss is greater in proportion as the amount of coal burnt becomes less in quantity. Perhaps there is no single application of heat in which the loss is greater than in that applied to the melting of metals in crucibles. In this metallurgical operation the fire is often large, and urged to its utmost intensity, until the metal has reached the proper degree of fusion, when the crucible is removed and the fire abandoned.

This will apply in almost any case where an intense degree of heat is required, and its use confined to certain fixed or arbitrary working hours. In this respect liquid or gaseous fuels have an advantage over solid fuels, as they need not be lighted until the last moment, the nature of the fuel permitting a concentration of heat at any desired point of application, and in any degree of intensity; it is also at all times under perfect control, and the supply may be instantly cut off when no longer required.

* **Gas-Fired Steam Boilers.** "There is no doubt but that the present method of burning coal under steam boilers is a wasteful process, as compared with making the coal into gas and using it in that form, for it has to be turned into gas in the furnace before any benefit can be derived from it. See also page 183 to 186.

"This unquestionably is a loss, for a boiler furnace is a poor gas retort. Moreover, the coke resulting is available and still valuable for heating gas retorts.

"Large companies only can afford to erect gas works. One, the John Russell Cutlery Company, of Turner's Falls, Mass., has done so. They say that they show a saving of 25 to 30 per cent over the use of coal, and are not yet working to the best advantage in the gas plant. The large saving comes in increased production per forge per man. A hammer man will do from 25 to 30 per cent more work with a gas than with a coal fire.

"This alludes chiefly to the use of gas for heating steel, but it would also apply to making steam. It would save much dirty work around steam plants if gas could be generally introduced, and the "low water" engineer would have a much better time, for he could have his gas fire much easier than he could his coal fire; also, the pressure would be steadier, and, in many minor ways well known to engineers, great advantages would ensue.

"The Philadelphia *Record* says that the problem of obtaining a cheaper fuel than coal for locomotives, which has long bothered railroad men, seems likely to be solved soon by experiments now being made with gas. A very good test of the new fuel has just been made at the works of the Electric Light Company in West Chester, which, since the fire which destroyed the old plant several months ago, have been dependent for their motive power on the Shaw locomotive.

"Instead of coal, gas mixed with air has been used in the locomotive with entire success in generating power to drive the dynamos. With larger machines for producing and mixing the gas, it is believed that power enough can be obtained for driving locomotives with trains, and a special car is now being built at New York to hold a large machine of the kind used in mixing the gas and the storage receivers.

"This will be attached to the locomotive, and tests will be made soon, probably on the main line of the Pennsylvania Railroad or the short branch line from West Chester to Phœnixville. The experiments at West Chester have been made under the direction of Jackson Richards, Master Mechanic of the Reading Railroad's Norristown, Germantown, North Pennsylvania, and Bound Brook routes, and he is sanguine of the success of the new fuel."

* The *Engineer*, April 21, 1888.

In a report on its workings Mr. Richards says:—

"I am satisfied in my own mind that, if machines large enough for locomotives are built with a reserve power, it will be a great advantage and saving to burn gas as fuel for railroad purposes. Having some thirty odd years' experience in the construction and management of locomotives, I can speak with confidence on the subject. I claim, in the first place, that the saving in burning gas instead of coal will be very great; for with the present system only about 45 per cent of the fuel is used, 55 per cent going to waste, while with the 'Caloric King' to commingle the gas and air, the combustion is so perfect that nothing is lost. To illustrate my meaning, it is only necessary to mention the fact—well known to gas manufacturers—that one ton of coal will make about eleven thousand cubic feet of gas, which gas, commingled with air and burnt through the 'Caloric King,' will do more railroad work than any two tons of coal, besides giving the company an additional profit from the sale of coke.

"The next saving, resulting from taking off the back pressure, amounts to 20 per cent, while doing away with the disagreeable noise of the exhaust, adding this strength to the engine. Another advantage to railroad companies is the doing away with all smoke, soot, and cinders, thus saving the heavy damages that companies annually pay for property destroyed along their lines."

* **Substitutes for Coal in the Household.** The introduction of some simple and economical method of providing dwelling-houses with ample supplies of heat for warming, cooking, and other domestic purposes, as a substitute for the present general use of coal, is one of the reforms in domestic economy which the near future may have in store for the sorely tried housekeeper of to-day. The demand for substantial reform in this direction is loud and imperative. The use of solid fuel, in the form of coal, for example, in the manner in which we consume it in our stoves, heaters, and ranges is probably as extravagant, wasteful, troublesome, and dirty, and generally unsatisfactory a method of providing this necessary convenience of the household as could be devised. In addition to the annoyance and expense of having coal hauled from the yards and dumped into our cellars, from which it must be dragged laboriously to every story of the house where it is needed, we must at present suffer the annoyance of knowing that we buy at the outset 10 to 15 per cent of worthless material in the form of ash, that must be afterwards laboriously gathered up and conveyed to the barrel or box provided for its reception, and that we blow out at our chimneys about three quarters of the heat that is given out by combustion.

* The *Manufacturer and Builder*, June, 1881.

* **Water Gas.** "A water gas — that is, a gas resulting from the decomposition of steam by contact with incandescent carbon — if it can be made cheaply, possesses qualities most desirable in a fuel; viz., inflammability and intensity. Composed of hydrogen and carbonic oxide, it is free from the undesirable element, nitrogen.

"If carbonic oxide, representing the maximum flame intensity (among practical gases), and hydrogen, with but little less of that quality, and an even greater 'useful value,' as Percy expresses it, do not furnish the very highest order of fuel, then science does not yet know where to seek it.

"Fortunately, too, it is a fuel obtainable at the lowest cost, though this is a recent achievement. For more than a half century inventors of different nationalities have racked their brains for some method by which water gas could be produced in large quantities inexpensively for the industrial arts; but various defects have invariably attached to the systems proposed, and rendered them unsuccessful."

The extracts from the report of Barr on Water Gas, and by Dr. Gideon Moore on the Strong Process are drawn upon at some length, as it is the conviction of most engineers that a gaseous fuel of some sort, from being one of the "pressing needs of the present day," has become a necessity, and so great an advantage to the manufactures and the arts, that, whatever the outcome of the present grand discovery of natural gas, men who have once used it will never return to solid fuel. "*Gas in some form is the fuel of the future.*"

M. H. Strong's Process for Generating Fuel Gas. "Adopting the economic principle of interior combustion throughout, viz., burning the coal in a primary chamber or generator and the products of its partial combustion in a secondary one, wherein the heat is stored for subsequent utilization, there are novel features in the Strong process which give it very definite advantages in the rapid and economic generation of a combustible gas of remarkable purity and efficiency for fuel purposes.

"The generator is charged with lump coal or coke, entered at the door in its side or from above by the opening left by the hopper, which is removable by means of a lever and tramway. An air blast enters below the hydraulic grate bars, which drives the fire, and forces over into the adjoining chambers, laid up with loose fire brick, like a Whitwell stove, the products of partial combustion (Siemens gas), which are ignited therein by a second blast entering through a perforated tiling, and burn downwards among the brickwork.

* Wm. Barr: "The Combustion of Coal."

"The third chamber, filled like the second with refractory material, absorbs a part, at least, of the heat from the waste products, which escape at the top through an open valve.

"When the coal has attained a heat of, say red to bright red, the brick of the superheater (as the secondary chambers are termed) shows orange to white.

"The air blasts are then shut off, the valve before mentioned is closed, and *steam* is admitted just below.

"Passing, it becomes intensely heated by contact with the bricks, from which it emerges into the top of the generator, where it meets a shower of coal dust sifted downwards from the hopper, by means of an Archimedian screw slowly revolved.

"The steam has acquired such an increment of heat, by contact with the dust carbon, a mutual decomposition immediately ensues, and the gases resulting pass downward through the bed of coal, and out below the grate bars into the hydraulic main.

"Astonishing as this original method of decomposition may appear, there is no doubt of its occurrence at this point, as during the earlier experiments the gases were allowed to escape from the generator without passing over the incandescent coal. There was found, however, an excess of carbonic acid in the product, and some unconverted particles of carbon were carried over. Both these defects were remedied by the passage of the gases though the burning coal, the carbonic acid changing to oxide of carbon, and the unburnt dust being arrested and utilized for fuel.

"The theory that the rapidity in evolution of the gas is proportioned to the reduced size of the particles of the carbon is fully confirmed by tests made on pulverized peat, during which the volume of the gas for a given period was increased about 50 per cent as compared with the coal slack.

"The operations of the apparatus at Mount Vernon, in New York, where experimental practice has extended through the year, substantiate the claim that a pure water gas can be obtained at the expenditure of not over two thousand two hundred and forty pounds of coal for each fifty thousand cubic feet. This includes the quantity burned under the boiler, which amounts to from 25 to 30 per cent of the whole. But it would seem that this considerable amount expended in the generation of steam may be saved by a simple utilization of the heat of the alternating waste and gaseous portions which, under these experiments, escaped at from 800° to 1,200° Fahr."

COMPARATIVE VALUE OF THE STRONG GAS AS A FUEL.

"As has already been shown, the Strong gas possesses a heating power of 8,798 units and a flame temperature of 5,483° Fahr. One cubic foot of the gas, weighing, at 62° Fahr., 0.0411 pounds, requires for its perfect combustion 2.47 cubic feet of air, and yields 3.027 cubic feet of products of combustion, of which 0.610 cubic feet is aqueous vapor, and 2.417 cubic feet is permanent gases.

"In the combustion of gaseous fuel, under normal conditions and with perfect utilization of the heat of the fire gases, the only loss of heat is due to radiation.

"Allowing 10 per cent as the probable extent of this waste, we have, for the effective heating power of the Strong gas, 7,918 units per pound; or 100 pounds of pure anthracite (yielding, as has previously been shown, 228.22 pounds of gas) would develop in practice a heating effect equal to 228.22 x 7,917.91=1,807,025 units of heat.

"The theoretical heating effect of coal being 13,000 units, the 100 pounds of coal would, if directly burned, develop 1,300,000 units, of which, however, but about 50 per cent, or 650,000 units, would be realized under ordinary conditions in practice; hence the practical heating effect of the gas stands to that of the coal from which it was directly derived as 2.78 to 1.

"In the manufacture, however, there is a large consumption of coal for heating the generator and for the production of steam. According to the inventor's figures, 50 pounds of coal will produce 1,000 cubic feet of gas, weighing 41.16 pounds, and possessing the theoretical heating effect of 362,113 units, of which 325,902 would be realized in practice. Fifty pounds of coal possesses the theoretical heating effect of 650,000 units, of which but 325,000 would be realized in practice under ordinary conditions and by continuous use, as in the generation of steam.

"Hence, in practice, and under equal conditions as to radiation and continuous use, the gas will produce the full heating effect of the coal consumed in making it.

"The case is, however, very different in the numerous class of applications, in which the cheapest grades of coals cannot be used. Thus, with ordinary steam and manufacturing coal, of which the price in New York is at present $4.50 a ton, the 50 pounds of coal would cost 10 cents, which, contrasted with the average cost of the Strong gas, 7 cents, shows the great economic advantages of the latter.

"The comparison becomes still more favorable to gas fuel if applied to *ordinary domestic uses.* In that department it is generally conceded that 10 per cent of the theoretic heating power of coal is the best result obtained, so that in these uses gas would have an advantage of about 5.57 to 1.

"Another feature worthy of special comment is the *intensity of combustion* of a gas fuel. The theoretic power of the Strong gas is 5,483° Fahr., and the relation of this fact to rapid and economic operation is too manifest to require argument. A furnace will often stand indefinitely at a temperature just short of that necessary to accomplish its work, at an incalculable loss of time, money, and temper, and sometimes to the serious disadvantage of the product. The writer has seen a small experimental reverberatory for the burning of this gas ready to charge in 12 minutes from lighting, and iron melted therein in 8 minutes after.

"Again the *constancy of this gas flame* is another marked advantage, and will enable the mechanic, *once the proper admixture of air is ascertained*, to wield a heat adapted to his special wants, to maintain a uniform temperature, and obtain a uniform result in time, cost, and quality.

"**The extraordinary purity of the gas** derived by this system is another exceedingly important fact. Analysis by Dr. Moore proves that the unpurified gas contains about 12.90 grains of sulphur, which is considerably less than the legal limitation for purified gas in London.

"But the absence of any large percentage of non-combustible constituents is far more important, as will be observed by the following table:—

Oxygen	0.77	Light carburetted hydrogen,	4.11
Carbonic acid	2.05	Carbonic oxide	35.88
Nitrogen	4.43	Hydrogen	52.76

"It is in striking contrast to that produced by the Siemens furnace, which, at about the same cost, contains about two thirds of non-combustibles. This serious drawback has been a characteristic of all cheap gases heretofore, and is a fatal objection in any method aiming to supply the general demands of a fuel gas. Aside from the fact that such a heavy dilution impairs the efficiency and the value of a gas to an extent not generally understood, the addition of such a useless volume would necessitate an excessive size and cost of mains for its distribution.

"The most striking advantages of the Strong process are:—

1st. The extreme rapidity with which the gases are generated in large volumes.

2d. The variety and low cost of materials which may be employed.

3d. The remarkable purity of the product.

4th. The economy of the labor involved.

5th. Its value as a substitute for other forms of solid or gaseous fuel, in the arts and for domestic use.

6th. Its application for illuminating purposes, either after previously charging it with illuminating substances, as a substitute for ordinary illuminating gas or as a diluent for very rich coal gas."

The attention of the public having been so often drawn to the grand success of natural gas as an every-day fuel, gas engineers have been busy in devising apparatus for the cheap and successful manufacture of fuel gas.

In presenting the merits of the Peter English process for the manufacture of water and fuel gas from the crude oil and decomposed steam, we do so without endeavoring to show its superiority over all others, but as furnishing a reference to one of the important and successful methods of supplying a gaseous fuel and superior illuminant. This, with a table of the cost of gas in the several cities, will close our subject of gases and their production and application to heating, cooking, and other uses. (See pages 198 and 199.)

* A sample of gas taken from the city main, Titusville, gives the following percentage of constituents, as tested by the latest and most improved instruments: —

	Per Cent.
Illuminants	11.09
Carbonic oxide	23.20
Carbonic acid	1.11
Hydrogen	48.50
Marsh gas	16.10
	100.00

The specific gravity varies from 0.60 to 0.67. Concerning the question whether this can be considered as a fixed gas, I have to make the following statement: —

The gas was submitted to a temperature of 30° below zero, Fahr., in such a manner that one cubic foot of gas required eighty minutes to travel through the refrigerating apparatus. One cubic foot of gas yielded 2.97 per cent of a condensed liquid, which on examination was found to be pure water without oils. Another test, made at a temperature of 15° below zero, Fahr., gave 2.10 per cent of water.

In order to ascertain the behavior of the gas under large pressure, I submitted a measured amount to a pressure of thirty pounds, by means of a high column of mercury, simultaneously cooling it to a temperature of 15° below zero. This test did not show any condensation of the water or oils.

These experiments will plainly show that the gas can be considered to be a fixed gas, having been submitted to these severe tests, and even stands superior, in respect to condensation, to coal gas, which I tested at various places, yielding up to 3.5 per cent of oil, consisting of benzole, toluole, hylole, and traces of naphthaline.

* F. Salathie, Ph. D., Manufacturing Chemist, Titusville, Pa.

*"We further guarantee specifically, with the labor of one man in twelve hours, in our six-inch apparatus, the size best adapted to small works, to *make forty thousand cubic feet of twenty-two candle-power gas, using not to exceed the following:* —

"Fifty pounds of hard coke or anthracite coal, five, to five and one-half, gallons of crude oil per one thousand cubic feet of gas (with an allowance of ¾ per cent for purification). In larger works we guarantee better results from the same labor, as the same man will run a large cupola, of three times the above capacity, just as easily, or will run two turns, 'blowing a heat' on one while 'making a run' on the other. Furthermore, our apparatus must come up to our specifications and guarantees of results in every particular, or it will be removed at our own cost from the works, and nothing demanded.

"To emphasize, we call attention to one instance where our gas permanently displaced and succeeded coke in heating iron rods for the manufacture of horseshoe nails, in one of the most noted works of the kind in America.

"We have been assured by the above company that they would pay $1 per one thousand cubic feet for our gas rather than go back to solid fuel.

Advantages and claims: —

"1st. The use, if desirable, of crude petroleum in the manufacture of water gas.

"2d. The economy thus effected is not approached by any other system.

"3d. The safety from risk, as well as the saving from evaporation, in using crude oil rather than naphtha or benzine is a great feature.

"4th. The first cost of the plant, as well as the future expense for repairs, is less than any other, guaranteeing like results.

"5th. The handling of the cupola and the operation of the entire system is so simple and so easily acquired, that a green hand is frequently left in charge after one week's instruction."

From the above we make the following estimate: —

Cost per 1,000 cubic feet of gas: 50 pounds coal @ $2.50 = 6.2 cents; 5½ gallons crude petroleum @ 3 cents = 16.5. Labor @ $1.50 per day = 3.8 cents. Total 26.5 cents per 1,000 cubic feet. Weight of 1,000 cubic feet of gas (sp. gr. .60) 1,000 x .045 = 45 pounds — equivalent to as many pounds of coal in practical calorifi[illegible] See Table No. 3 on the heat of Water Gas.

*The McKay Manufacturing Company, Titusville, Pa.

AIR AND GAS CARBURETTED.

***Gas from Crude Petroleum, Paraffine Oil, and Residuum.** A large number of patents have been taken out for the manufacture of illuminating gas from crude petroleum and the dense products of its manufacture. The general principle on which all these processes depend for operation consists in the distillation of the materials at a temperature sufficiently elevated to crack the petroleum compounds into gaseous products.

This method of preparing illuminating gas is quite extensively used for lighting large manufactories and villages and small towns.

Carburetors. The idea of saturating illuminating gas with the vapors of volatile hydrocarbons for the purpose of increasing its illuminating power was entertained long before the discovery of petroleum in commercial quantities. The low price at which these products could be obtained after petroleum became extensively produced led to the invention of a large number of machines in a great variety of form and principle of construction.

The number patented in England, France, Germany, and the United States prior to 1880 must be in the neighborhood of one thousand. The first patents that were issued were for inventions that produced a complete or partial saturation of the gas or air without in any manner controlling the evaporation or temperature. Evaporation was induced and rendered more constant by the construction of a sort of a labyrinth, through which the gas or air was forced. This method of carburetion, although very effectual, was still open to objections, and did not furnish uniform results; but the difficulty was removed by an invention by which the tank in which the naphtha was being distilled was submerged in a wooden tank of water. The great specific heat of the water caused it to give out heat, equalizing the temperature, producing a uniform distillation, and consequently a uniform partial saturation of the air or gas.

This contrivance may be said to have rendered the carbureting of air a success, and a large number of machines have been constructed on this principle. The gradual fractional distillation results in the accumulation of a residue in the labyrinth too dense for evaporation with sufficient rapidity to properly carburet the air. Many attempts have been made to remedy this defect, in which success has been attained by a remarkable invention of recent date.

This machine is called the metrical carburetor, and is used for carbureting either gas or air. The name designates a peculiar feature of the instrument—that it measures the amount of carbureting fluid to either the gas or the air.

***S. F. Peckham, U. S. Census Report.**

One and a half to two gallons of light naphtha are measured to one thousand cubic feet of ordinary street gas, or three to six gallons of gasoline to one thousand cubic feet of air, according to the purpose for which the gas is to be used. In regard to economy, safety, and perfect operation, this metrical carburetor far excels all others hitherto invented.

EXPERIMENTS WITH GASOLINE AND COAL GAS.

Experiment 1. Twelve Argand burners were connected to coal gas, 12 to air gas. A meter was attached to each 12 burners. The burners were matched and the light as near alike as possible. When the meter on the coal gas registered 1,000 cubic feet, the meter on the air gas registered 560 feet.

Experiment 2. Four lava tip 12 c. f. burners were used with gas diluted suitable for illuminating, which would be equivalent to using a mixer. One hour, gas consumed was $13\frac{4}{12}$ cubic feet, of which 12 cubic feet was pure air.

Experiment 3. Same burners, same time, temperature 54°, diluted as before. Fifteen cubic feet of gas consumed, $13\frac{1}{10}$ of which was pure air; 8 ounces of gasoline consumed (a gallon of 83° gasoline weighs 85 ounces).

Experiment 4. Forty-five ounces of gasoline was used, producing $56\frac{2}{10}$ feet of gas, of which $46\frac{2}{10}$ was pure air under an average temperature of 42°.

Experiment 5. A small cast-iron heating furnace, made by the Archer & Pancoast Manufacturing Co. of New York, was used one hour, consuming 12 ounces of gasoline; cost per hour, 2.82 cents, with 86° gasoline at 20 cents per gallon.

The heat was such that a pair of 2½-pound soldering coppers were at a working heat in 5 minutes, commencing with the furnace cold, and 1 pair 6-pound coppers in 7½ minutes. When the furnace was hot, a pair of 2½-pound coppers were hot in 1½ minutes, and at a forging heat in 3 minutes. Coal gas was used in the same furnace, furnishing about the same results in heat, but consuming 19 cubic feet per hour, costing 5 8-10 cents per hour, with gas at $3 per 1,000 feet.

RECAPITULATION.

There are four varieties of gas available for fuel; viz., *common illuminating gas, water gas, generator gas, and carburetted gas.*

Illuminating gas consists mainly of carburetted hydrogen. It has a high calorific value, but only the volatile constituents of the coal can be utilized in its manufacture.

Water gas is a mixture of carbonic oxide with hydrogen. Both the coke and the volatile portion of the coal are utilized.

Generator gas consists of carbonic oxide mingled with a large proportion of incombustible gases.

Carburetted gas is common gas, or air carburetted with gasoline or naphtha.

Of the total heating capacity of solid fuel, only a small percentage is utilized in metallurgic operations and in ordinary domestic use.

The advantages connected with the use of a gas fuel may be enumerated as follows: —

1st. The cost, labor, and inconvenience of handling a heavy material are avoided, the fuel being capable of easy distribution.

2d. It is in a form also free from those mineral impurities which involve a large residual waste, besides impairing combustion.

3d. It is free also (if it is a purely combustible gas) from those ingredients which, in the present method of burning, involve even greater loss than the cause last mentioned.

4th. It is in precisely the condition to unite perfectly and instantaneously with the oxygen of the air, thus securing a thorough combustion.

5th. Hence it gives an immediate and uniform result, and its flame temperature is constant.

6th. The intense and steady heat of the flame just mentioned, saves both time and money, by presenting an even fire surface at the time of ignition.

7th. It is a fire capable of concentration upon the precise point where the fire is wanted, and one that is thoroughly under control, the turning of a valve starting, graduating, and stopping the combustion at will.

8th. The general cleanliness of the system, no dirt or residuals being left.

9th. The decided advantage, from a sanitary standpoint, of simply *burning* combustible gases in our dwellings, instead of trying to *make* them as well, by means of the imperfect gas machines called stoves and furnaces, is one that should not be overlooked.

10th. A great source of economy in the use of a gaseous fuel is the utilizing the poorer grades of coal which would otherwise be wasted.

CHAPTER XIV

UNSAFE BOILERS AND STEAM GENERATORS.

PART III.

BEFORE taking up the liquid or gaseous fuels, we called attention to the fact that the regular order of our subjects was necessarily broken by admitting a chapter on the construction of furnaces before we had considered all the fuels and their relation to the important matter of Part I., the "Chemistry of Combustion."

But as the fine fuels — the slack, and waste, and the powdered coals — could not well come in later, so the furnaces, which are adapted to burn these coals, claimed attention in the general section of solid fuels, and the conditions necessary to their combustion.

It was not the writer's original intention to attempt any general history of the steam boiler, ancient or modern, since whole volumes have been and might be filled with considerations of materials, and details of the various constructions, which have from time to time claimed the attention of manufacturers and engineers.

It seems desirable, however, to review somewhat the two distinctive classes of boilers — the wrought-iron "return tubular" and the wrought and steel sectional boilers, confining these remarks, however, more to cast-iron boilers and radiators than to wrought materials, or construction employed in the production of power, these being so fully treated by former writers.

In discussing furnaces and boilers, we shall consider those mainly employed and adapted to the warming and ventilation of buildings, with perhaps the exception of the cast and wrought iron constructions, which are not limited to any particular class of work. These deserve a candid and careful consideration.

There is a growing conviction that whatever else, all boilers for heating *dwellings*, *schoolhouses*, *churches*, and other public buildings should be of the non-explosive class. No chances should be undert[illegible] human life in its most unprotected and helpless condition pay[illegible] The stupidity, ignorance, or carelessness — faculties mainly a[illegible]

often employed in the care and management of steam boilers — should have no opportunity to display these traits (inherited or otherwise).

There are two great and unmitigated evils, that cling like a pestilence around the neck of individuals and society,— *intemperance and boiler explosions,— both reckless and needless squanderers of human life and happiness,* — the first largely responsible for the second.

To say that any great evil or scourge is *preventable*, and yet tamely endured by a generally intelligent and educated community, is to sum up the whole grave indictment in two words, *Wanton Waste.*

There may be no question which is the worst destroyer of life and property, or a need to show that both of these terrors are largely an inheritance, an inherited and transmitted disease following us down from the dark ages, as did negro slavery, and its attendant disregard of human life and happiness.

But to say that they exist, that they thrive and grow all about us, strewing their broad pathway with the wrecks and wreckage of the most precious cargoes ever freighted by sea or land, is to call a halt! while we briefly consider the way we walk, and how our steps will look to those that follow after us and gaze at the tracks made in the full light and knowledge of the nineteenth century.

If a "recklessness of human life is the essence of barbarism," every steam-boiler explosion is a similar relic, if the owner or user has not done all in their power to prevent disaster, while invoking the genius of warmth and power.

Dr. Alban, of Plau, in Meclenberg, is given the credit of enunciating the grand idea, "*that all boilers should be so constructed that their explosions or ruptures from whatever cause should not be dangerous to human life.*" Who first commenced to utilize this grand idea by constructing and putting into use a safe steam generator, is perhaps harder to determine.

It requires but little reflection to see that this subject has not received the searching examination that its magnitude and importance demand. Acute intellects have for over a century been employed in perfecting the steam engine, it being the more showy and attractive machine; while the boiler and generator has been left to the crude notions of a class of mechanics whose main qualifications seem to be the curving of a plate, the use of the hammer and drift pin. The question of safety as connected with the form and construction of boilers seems to have been generally ignored until within the past few years, when, as steam came more and more into general demand, followed by a corresponding increase of pressure and accidents, destroying human life and property without limit, there have been frantic efforts to ascertain practically the reason why so many boilers explode. The results so far have been anything but satisfactory.

That boiler explosions are preventable to a degree, even where the large shell is employed, is shown by the reduction of accidents; and the detection of weakness, before rupture occurs, by the careful and regular inspection of insurance companies, who, having a money interest in every boiler they issue a policy upon, leave no stone unturned to secure proper construction, setting, and care afterwards.

One company, The American, of New York, goes so far as to publish a handsome and creditable book of over two hundred pages on "The useful things to know about steam boilers." G. B. N. Tower, editor.

The Hartford Company do even better than this, and publish a monthly called "The Locomotive," in which may be found not only much practical matter of interest to engineers, but which would prove of the greatest importance to all parties who either own or operate a boiler in any way.

Here may also be found a detailed list of all the explosions that occur, with data obtained from the inspectors, without which reports of boiler explosions should be taken with a large margin for corrections. In another place we insert a summary of the Inspector's report for the years 1887 and 1888.

That the same causes which so often rupture and destroy a shell boiler will neither rupture nor destroy a sectional boiler of wrought or cast tubes, is certainly true, and this, irrespective of the material of which the tubes are made.

That it is the *shell* of the wrought-iron boiler, and *not the tubes*, which explodes, is well known; and it is upon the shell that all the skill of the maker, all the care of the fireman, is expended. True, if he get his water below the tubes, they will expand, and leak, and require repairs; but, should he get low water *on the shell*, uncover even a foot of it at the water line, and then pump it up suddenly,—well, he *may* survive to affirm there was plenty of water, but generally *a coroner's jury renders the usual verdict.*

It is not a little singular that the real key to this question should have escaped the education and mechanical judgment of engineers or even of persons without any special or technical training.

Take up almost any of the numberless books on the steam boiler, and see with what care and earnestness every detail of construction and materials is insisted upon, from the manufacture of the iron to its shearing, punching, drilling, riveting, bracing, and staying, to the curve and thickness of the head, to the diam ength of the tubes; and finally, to secure the accuracy and ired, special machines are designed and employed, each of g a small fortune to construct and operate.

And when all is done, what have we? What go we out for to see?

A cylinder of from two to six feet in diameter and from eight to sixteen feet long has been made up of separate plates of various thicknesses, rolled, punched, and riveted together,— we may fairly say *sewed together*,— the rivets representing the stitches in the iron seam, on each one of which the value of the whole structure depends, as, if under the ordeal of fire and water, but one of the thousand rivets yields, the next receives a double strain, and so on, until the inevitable rupture and explosion follow.

It was not the author's intention to enter at great length into a subject already familiar to readers of engineering and scientific journals, and to press a point where he might be supposed to be influenced by even a remote interest in sectional boilers. But the last terrible cry of *midnight wreck, disaster, suffering, and death* comes to us while our type is standing on the printer's form.

Certainly, in a matter of this importance no false scruple should deter a writer from stating his honest convictions, or from giving a place to what is but the common history of the times, and what may be expected in the future unless there is a radical change in the methods and machines for the generation of heat.

Condensing the *Globe* and *Herald* reports of Feb. 18, 1889, we read as follows: —

"*Hartford Hotel Horror! Boiler in Basement Explodes! Eighteen Dead Taken from the Ruins! Ten Maimed Victims in the Hospital! Midnight Search for the Entombed! Tales of Suffering from the Wreck! Arrest of the Engineer and Commitment to Jail!*"

The Park Central Hotel was a comparatively new and substantial building one hundred and twenty-five feet long and forty feet wide, having some forty rooms, and built at an expense of about $100,000. Later an annex was added containing twenty-four rooms; these were for the servants and employés.

The guests, regular boarders, transients, and servants were asleep.

It was five o'clock all over New England when the fact was announced in Hartford by a shock that made its streets tremble, and broke the glass in many houses near the depot of the New York, New England & Hartford Railroad. It was a rumble like an earthquake, a tremor like a falling mountain, and a roar like distant thunder.

Then the big hotel with its brick and granite walls was seen to sway to and fro like a drunken man. A moment it tottered as if uncertain what to do, and then it came toppling over, filling High and Alley streets with débris and the air with dust and smoke.

The Central Park Hotel was no more. But where were the fifty or more people who were quietly sleeping in their beds?

Like the dreaming Turk in Halleck's famous poem "They woke to die mid flame and smoke,"— or those that did not die lingered on through the fight for life and rescue made by the brave firemen and police, pinned down by heavy timbers, suffocated by dust and smoke, and finally drenched by ice-cold water until in their agony they coveted the fate of those who by instant death had escaped horrors so unsupportable. Of this time, the proprietor, Mr. Ketchum, said: "I don't know much about the first crash; I was asleep. I had no presentiment of the coming danger. All at once I woke up; there was a heavy weight upon my back and legs, so that I could not move. I do not remember hearing a sound of any kind save the cries of my wife, who was moaning and asking for help that I could not render her. I made every possible effort to free myself, but it was of no use! I was firmly vised, and the pain I suffered was intense. Again and again I spoke to my wife, trying to cheer her; the only answer was a moan.

"Then the smoke came up from below to blind and choke me, and, to add to my agony, I was drenched with ice-cold water and nearly drowned; after this I was fearfully cold, and seemed likely to freeze to death. I could hear the men at work outside my prison, but my voice could not reach them.

"There seemed nothing left to do but to die. I wished death would come, and come soon. In this frame of mind I lay, I don't know how long — it seemed an eternity."

There is much more harrowing recital of this kind, but sensational details are not sought here. The plain facts were terrible enough, and we turn to some words of the engineer and others that went down in the wreck.

The engineer, Alex Thuer, was found near the ruins, and taken to the station. When asked to give his relation of the disaster, he said that he was willing to tell all that he knew about it, but this was not much.

"I have been engineer of the Park Central for a number of years, and up to the putting in of the new boiler four and a half years ago. Soon after, Amos Risley was employed as my assistant, and we divided the time on duty. It was our usual custom to bank the fires at twelve o'clock Saturday and Sunday nights, and on these nights no one remained in the boiler-room. When we left the fires with the steam on for the building, there would be *from forty to sixty po[illegible] of steam.*

"I had been off duty since Sunday noon, and was [illegible]n at six this morning. Risley was on from twelve o'clock yesterd[illegible]idnight.

I called to see him at half-past ten, but remained only a few minutes. I then went to my room in the annex, and retired at twenty minutes past eleven. I heard Risley go to his room next to mine soon after midnight, and knew no more until the crash this morning."

"How about the boiler when it was left nights? Was it possible for any cold water to get into the boiler after the boiler-room had been closed for the night?"

"Yes, it was possible. A number of times the trap to the reservoir, where the water from the condensed steam was stored, has worked badly, and at times leaked.

"But the boiler was left full of water every night, and it does not seem possible that it could get out."

"If the boiler had been empty, and the trap had acted as it has on a number of occasions, the cold water would flow into the boiler, *which would cause an explosion.*"

"*The boiler was inspected last fall, and the certificate hung in the engine-room.*"

Shades of Watt! What nonsense, what idiocy, has been talked of the agent you discovered! The boiler was always full of water; it could not get out; but, if it did, and any more water (hot!) from the reservoir got in, then the boiler would explode!

Yes! The certificate hung in the engine-room; the boiler was all right—it had plenty of water; the fires were banked; the engineer was sober, at least at the time—"he had not drank anything for over four years except an occasional glass of small beer."

Yes, again,—all was fair, secure, and safe to outward seeming; but, under all these favorable outward conditions, a force was generated, and lay slumbering in the basement, sufficient to burst its bonds, tear its way through whatever was over and above, and demolish a five-story building, and to bury in its ruins the people who trusted in their outwardly fair and common condition—so common that, with all the terrible warnings and disasters that constantly follow in the track of shell and explosive boilers, it is the exception to-day to find any other under hotels and commercial buildings, while hundreds are placed each year under *schoolhouses*, *churches*, and *private dwellings!*

A list of the killed and wounded seems to be a fitting period to this last record of *human frailty*, *ignorance*, and *cupidity*, as exhibited in an *unsafe boiler construction*, run and operated under conditions that from first to last invite the disaster that sooner or later overtakes it.

FIFTEEN BODIES TAKEN OUT.

All but Three Identified — Others Still in the Ruins.

The number of persons killed will reach twenty, and possibly thirty.

Dwight H. Buell, Hartford; Louis H. Bronson, wife, and ten-year-old daughter; George Ketchum, brother of proprietor of hotel; Eddie Ketchum, thirteen-year-old son of the proprietor; J. C. Hill, of New York; E. George Gains, night porter, of Hartford; J. George Engler, of Norwich, clerk at Marwick's drug store; J. M. Horseman, of Brooklyn, N. Y.; A. F. Tillottson, of Cincinnati, O.; George W. Root, drummer for Wait, Williams & Co., dealers in oils, Boston.

The unknown are men who are horribly mangled. Added to these the following are known to be in the ruins: —

Rev. Dr. Perrin and wife, Hartford; A. F. Whiting and wife; Edward Perry, the night clerk.

These are all that are known to be dead, but it is possible a few transients arrived on the late trains after the night clerk left at ten o'clock last night.

Telegrams have been received giving instructions in case of the finding of the bodies of E. Rowland and wife, of New York; F. W. Brittain, of Birmingham, this State; and —— Dunnington, of Farmington, this State.

Mr. Rowland recently came into possession of $40,000 by the death of an uncle in Windsor, and was on his way to obtain his money. It is not known for a certainty that Mr. and Mrs. Rowland were in the hotel, but they were due in the city Saturday night, and could not be found at the other hotels. The others are also believed to be in the ruins.

With a few condensed remarks from the *Boston Daily Globe* of the 20th, we pass on to glance at one or two other late examples of the shell boiler, its care, management, and results.

"The unsafe boiler, incompetent engineer and fireman must go."

"Both of them are a standing menace to the safety of the community, and the wonder is that they have been allowed to remain so long."

John T. Daly, of the Inspector of Buildings Office, says: —

"Undoubtedly there are a great many unsafe buildings in this city, and boilers in charge of incompetent persons.

"In some large buildings the men in charge of boilers have also to assume the duties of janitors, shippers, etc., and I very often find an engineer who does not know whether his boiler conforms to legal requirements or safe conditions. I saw at one time a boiler whose normal pressure was sixty pounds, and the man in charge had hung a four-pound weight additional on the lever of the safety valve, raising its pressure to ninety pounds.

"I know of one place where the man who looks after the boiler also runs a lathe; and in many of the down-town restaurants, where boilers are used, the cooks and kitchen girls take general charge of them.

"There are many Back Bay houses that have boilers run at six or seven pounds pressure, and there are instances where one man or janitor looks after half a dozen.

"It may be of interest to know that in Boston last year fifteen hundred and fifteen boilers were examined from this office; of these nine hundred and twenty-three were found to conform to the law regarding fusible plugs, four hundred and ninety-one did not conform, and the condition of one hundred and one could not be ascertained from various causes."

*Boiler Explosion, St. Mary's Church, Fort Wayne, Ind.**

"The explosion of the boiler of the heating apparatus in St. Mary's Church, in this city, which occurred on Wednesday, January 13, between 12 and 1 P. M., made a complete wreck. St. Mary's Church was a large and stately edifice. The boiler was in the cellar, at the east end, under that portion of the church where the high altar is situated, and located in a recess built out from the east wall of the church. One portion of the force of the explosion apparently drove up through the floor overhead and out through the roof of the recessed portion, hurling that portion of the roof, which was of tin, over the parsonage, which is situated close by, east of the church. The other portion tore up the floor of the church, and demolished everything within its reach, as can be easily imagined from one of the boiler heads cutting its way to near the front door. The large stained-glass windows, with their frames, were blown into the middle of the street.

"So quick and violent was the force that many of the window frames were split from top to bottom, and the portions having the lugs upon them, which held them in the walls, were left in their places; at the same time the massive side walls were thrown out of line at the top, and now overhang about two feet from the perpendicular. The large windows, sash and all, away up in the belfry tower, were torn out. There is a double row of columns running through the church, which apparently sustained the roof.

"*A schoolhouse on the south side, immediately adjoining the church, is so shattered that it has been abandoned. The priest's residence, on the east, is in the same condition, and will have to be taken down. In fact, all is ruined.*

"Is it possible that the missing boiler sheet was blown to atoms? It is nowhere to be found. Even if it was a bad one, it held on long

* *Scientific American*, Feb. 6, 1886.

enough to create a force more destructive than dynamite, for that is generally local in its effects, whereas the boiler explosion was general and extended in its action.

"It is said that the safety valve was weighted to carry thirteen pounds of steam to the square inch. That would be reasonable for so large a church. But who knows what the condition of the valve itself was? Who knows whether it has ever lifted since it was started last fall?

"A boiler that will hold together long enough to cause such fearful havoc of life and property ought not to be blamed if it blew up, nor the makers censured. It would be interesting to know how much pressure it sustained before it gave out.

"It is safe to say that ignorance the most profound in the use of steam had charge of that boiler, and a fearful penalty has been the forfeit."

*Proper Care of Heating Boilers.**

"The newspaper sensation growing out of the fact that, on an unexpected visit of some reporters and members of the Brotherhood of Stationary Engineers to the boiler-house of the New York Steam Company, they found the *responsible* engineer asleep in his bedroom within the building, and the boilers in the charge of firemen, is not so bad an affair as the head-lines of our daily papers would lead the public to suppose. There is very little doubt that the intelligence of the firemen employed for this service is quite sufficient to secure the license granted by the Police Department, if they (the firemen) chose to pay the small fee connected therewith.

"At any rate, from the character of the plant, even assuming the grossest carelessness, no casualty could occur that would injure property other than the company's, though it might scald the firemen whose own neglect contributed to it.

"On the other hand, it has come within our knowledge that in a certain church that has lately had a heating and ventilating apparatus placed within it, in which there is a horizontal shell boiler, such boiler was burnt by water getting low, through the ignorance of the man in charge, when it was only one week in use.

"This is a case where the man in charge of a large shell boiler does not come within the jurisdiction of the Police Department, on account of the omission, or at least want of provision, in the law under which the Sanitary Police examine engineers. A tea-kettle or a boiler will come within the law and require a licensed engineer if it has an engine that one might carry under his arm attached to it; but the New York public schools, many of them with as much as one hundred horse-power

* *Sanitary Engineer*, Feb. 4, 1889.

in large shell boilers in their basements, are without licensed engineers, simply because they have no engine attached, and come under the head of heating apparatus. It is about time that something was done with regard to warming and heating apparatus for schools, churches, and other large buildings in which there are steam generators capable of explosion, so that they may come within the scope of the Sanitary Company of the New York Police Department."

*Serious Accident at Dell Brown's Hotel, Eagle Bridge, N. Y.**

"A serious accident occurred in the waiting-room of the Delaware & Hudson Canal Company, in Dell Brown's Hotel, at Eagle Bridge. The building is heated by steam, and a new heater was put in about three weeks ago by Fenderson & Co., of this city.

"A few minutes after 2 P. M., the boiler exploded with terrific force, hurling the occupants of the apartment in all directions.

"The windows and doors were blown out, and with them Adam E. Reynolds and Thomas McCann. The floor was torn up. The coals from the heater set fire to the woodwork, but the flames were extinguished by the water from the exploded boiler. The report of the explosion caused many persons to hasten to the scene, and a sad sight met their gaze. Scattered about the waiting-room in a helpless condition were several human beings, while another was suffering in the parlor, which is immediately over the waiting-room, and still another in the barber shop adjoining. A lady, who proved to be Mrs. G. E. Kirby, seemed to be the worst sufferer.

"Both of her legs were broken, and she is scalded and injured internally. There are grave doubts of her recovery. G. E. Kirby, her husband, is seriously injured about the back and hips, and is badly scalded. He is a commercial traveler in the employ of tobacconist Francis Shields, of Albany. They were on their way to spend Christmas with friends in Cambridge. Miss Ann Hogan, of West Hebron, had her nose cut almost off, and she is otherwise injured.

"Adam E. Reynolds, the station agent, a son of ex-Sheriff E. C. Reynolds, is very badly scalded. His left leg is severly cut. He was found in the snow about fifteen feet from the building, and near by him was Cornelius McCann, the telegraph operator, who had a bad scalp wound. There is a four-inch gash in the forehead, and one hand is burned in a shocking manner. C. E. Frost, conductor of the Rutland & Washington Division, and in point of service the oldest conductor in the employ of the Hudson & Delaware Company, had one leg injured, and is severely scalded. He entered the waiting-room just as the explosion occurred.

* *Boston Sunday Herald*, Dec. 23, 1888.

"Mrs. Dell Brown, wife of the proprietor of the hotel, was in the hotel parlor. She was hurled against the wall with great force, and sustained serious internal injuries. John Doyle, the hotel barber, was found senseless in his shop. He is not badly hurt. It is believed that the explosion was caused by the generation of gas in the heater. Suits for damages are certain, but the question is whether the Delaware & Hudson Canal Company or hotel proprietor, Dell Brown, shall be made the defendant. The east side of the hotel is a total wreck. The fierceness of the explosion was so great that it completely overturned the piano in the parlor. Pieces of the boiler were driven into the roof of the building, so that they could not be pulled out."

*Dangerous Steam Boilers in City Schools.**

"At a meeting of the Board of Education in this city recently, the Principal of the Grammar School No. 29, in Greenwich Street, asked permission to dismiss his school when the boilers for heating it were in danger of explosion. *The janitor, he said, was absent most of the time, and in his absence a drunken substitute had charge of the boilers.*

"It appeared that the Trustees had investigated the case, and taken measures to discharge the janitor, but that, through some mysterious agency, the papers had been lost.

"Evidently there was no question of his unfitness for the position he occupied, as the Trustees had already passed on his case, and the Principal knew the facts, and had fears for his own life and the lives of children in his care. The question, then, is, Who among the Trustees of the committee is responsible for this state of affairs?

"But there is no use dealing with an individual case, when, as a matter of fact, every schoolhouse in the cities of New York and Brooklyn, *in which there is a shell boiler, is unsafe* when steam is up under the present system of management.

"Under the law, as it stands, heating boilers are exempted from inspection, nor is it necessary for the person in charge of them to have any qualifications for the responsibility. Section 310 of chapter 437, New York Laws of 1885, says: 'It shall not be lawful for any persons, etc., to have, use, or operate within the city of New York any steam boiler or boilers, *except for heating purposes* and for railway locomotives.' The next section says: 'It shall not be lawful for any persons to operate or use any steam boiler to generate steam, *except for heating purposes* or for locomotives, or act as engineer, without having a certificate of qualification, etc., from the Sanitary Company of the Police Department.'"

The italicized portions of the quotations show the defects in our laws on these questions.

* *The Sanitary Engineer*, March 18, 1886.

"The clause was inserted to exempt small, low-pressure heating apparatus in private houses, and so far was obviously a proper measure; but it was never foreseen to what a dangerous extent the provision might be construed.

"Many of our schools have two or three fifty horse-power shell boilers in their basements. In many cases these boilers are separated by the width or length of the buildings. These boilers carry from five to forty pounds of steam, according to the whim of the janitor or as he may find it necessary to keep the building warm. His duties are of such a nature that he cannot be required to stay by his boilers during the hours of school, and consequently he cannot be held accountable for his absence from any particular place; and if he is a drunkard or lazy, or absents himself from his duties, there is no means of proving it, unless he is followed from morning till night. But it is not his proper duty to have charge of the boilers. The sweeping, dusting, and scrubbing of the rooms, with proper attention to the water closets and care of the property, are his duty; and an engineer, answerable to the principal and the janitor, should be appointed, who should be required to remain in charge of the boilers during the whole time the steam is on the buildings.

"This should be required by the Board of Education even now, during the winter or cold season; but, above all, our laws should be at once amended, so as to make it compulsory on all owners of steam boilers used for any purposes, except for private house heating and for locomotives, to employ engineers licensed by the proper local authorities, and all boilers whatsoever for making steam, except in private houses and for locomotives, should be inspected by the Sanitary Company of the Metropolitan Police.

"In the case of the school referred to, on visiting it, we found two shell boilers separated from each other by fully forty feet, and still in charge of the janitor's substitute, *who, at the time of our visit, showed the effects of liquor*, and who knew no more about taking care of a boiler and making steam than to open the fire door to keep the pressure down, the ash-pit door being open at the same time. When we pointed out to him what he was doing, he did not seem to have intelligence enough to comprehend the import of our exhortation.

"These same two boilers, although presumably of twenty horse-power each, were furnished with but one and one-quarter inch common safety valves (not more than one quarter the required area), and the automatic regulating dampers were out of order and inoperative."

*A Remarkable Explosion of a Steam-heating Boiler.**

"The *Worcester Daily Telegram* of October 5th gave a detailed account of an explosion of a patent boiler in the house of E. A. Chapin, at Chapinville, where the mills of E. A. Chapin & Co. are located. The explosion was loud and terrific and disastrous in its effect. There was no loss of life, but the inmates had a very narrow escape. When Mr. Chapin had remodeled his house, he had it furnished upon an elaborate scale, and put in a patent steam-heating boiler with safety attachments connected, for the purpose of heating his dwelling. Up to yesterday, however, as the mill near by was running, steam from the boiler-room supplied the house, and consequently the patent boiler in the basement was not given a trial. The mill recently shut down, and, owing to the frigid condition of the atmosphere yesterday, it was deemed advisable to start the fires under the new boiler.

"No one in the house had a clear idea how the boiler should be handled, but at the same time no danger was apprehended.

"Shortly after half-past seven o'clock Mr. Chapin went to the basement and had a rousing fire built under the boiler, and before leaving it supposed that everything was in proper shape. After going to a neighboring house, he returned and invited the hostler to visit the basement, that he might be given some instructions regarding the care of the boiler. The two walked scarce twenty-five yards from the door, when they were shocked by hearing a loud report, and saw the piazza and the front section of the house shattered to pieces. They realized what had taken place, and, fearing that the inmates had been killed, and that the building had been set on fire, they summoned all the available help possible.

"The building fortunately escaped fire, while the members of Mr. Chapin's family had a miraculous escape. Three minutes before the explosion took place, members of the family had stood directly over the spot where the boiler was located. All but Mrs. Chapin had left the house. She was at the time standing upon the piazza, where she had a thrilling experience. The first intimation that she had of anything wrong was when the foundation of the piazza was blown into the front yard, and she was well nigh buried beneath the shower of splinters and wrecked furniture. She was not seriously injured, but was given a severe shock, from the effects of which she did not recover for some time.

"An examination of the premises showed the wreck to have been complete. Scarcely an article in the house escaped, and the scene was a remarkable one.

* *Master Steam Fitter*, October, 1888.

"The boiler, when it exploded, was shattered into many pieces, which were hurled in all directions. The basement, after the explosion, looked as though an express train had been run through it, there being hardly any of the woodwork in it that was not shattered to splinters, while the foundations of the boiler and the cellar were blown down. Huge pieces of the flying boiler passed through the sitting-room floor, and stripped the carpet off, carrying it to the ceiling above, where it was found so firmly imbedded that it required the united efforts of three men to pull it down. The room was one mass of broken furniture and bric-a-brac. Hardly a single article escaped destruction. In fact, in every room on the ground floor the work of destruction was complete. On the second floor all articles of bric-a-brac, pictures, etc., were destroyed, and a stove, in which there was a fire, was blown across the room and wrecked; and it was only by great promptness that the building was saved from taking fire. The front of the house was almost wholly blown out, and the roof in several places was lifted. Every light of glass was broken.

"Mr. Chapin cannot correctly estimate his loss. The house cannot be repaired for less than $1,500, while the loss of furniture and bric-a-brac he believes will reach nearly $7,000, as the articles destroyed took a lifetime to collect, and cannot possibly be replaced. The loss is, of course, not covered by insurance, as the damage was not done by fire.

"Just what caused the explosion will probably never be known. Mr. Chapin believes that the proper quantity of water was run into the boiler before he started the fire; but, of course, he is not sure. It may have been due to the fact that the water run out, or that there was some defect with the safety valve; but, whatever the matter, it is evident that there was a big head of steam on when the boiler blew up. In reply to an inquiry from the ***Master Steam Fitter***, Mr. Chapin favored us with the following letter: —

"'CHAPINVILLE, MASS.

"'MASTER STEAM FITTER: The boiler that recently exploded, and destroyed the inside of my house, was a wrought-iron tubular boiler, about twelve horse-power, made by Wm. Allen & Sons, of Worcester, Mass., known as the Hunchback boiler. Have not used the boiler for two years; been kept full of water, and had three gauges at time of explosion.

"'Ten minutes before the explosion indicator indicated five pounds of steam. Safety valve worked all right twenty minutes before exploded. Boiler was put in by Braman Dow & Co., Worcester.

"'Boiler, I think, had been used three years. The valves of radiators in several rooms were open for steam to pass round the house. I know that the boiler was full of water.

"'I cannot see why boiler should explode, even if safety valve was tied down, with radiator valves open. One thing is sure — it did explode, making a terrible wreck.

E. A. CHAPIN.'"

BOILERS IN OFFICE AND RESIDENCE BUILDINGS.*

"The unsuspecting pedestrian, walking the streets of New York, is walking over *charged mines*. It is probably not an exaggeration to say that every fourth building on one of its large public thoroughfares has a boiler either directly under the sidewalk or just inside the building. The necessities of business and the lack of suitable space often make it practically impossible to do otherwise than place these boilers in such a position; and though, when thus placed, they may, indeed, be a menace to the public at large and the occupants of buildings, yet, on the other hand, the boilers are a necessity, and the question naturally arises as to what can be done to make them safe.

"Municipal inspection of boilers, as it is ordinarily carried out, is a mere farce, even where it exists. The inspection of the boiler insurance companies is more thorough, and affords more security, *but no inspection will make a boiler safe from over-pressure and mismanagement.*

"We do not wish to assail the ordinary shell boiler, particularly the horizontal multitubular variety. All boilers holding much water are, however, *magazines of stored energy*, and require only to be neglected or mismanaged to produce a result similar to that at Hartford. We ourselves know of a banking-house in New York where a new boiler was burned from neglect or mismanagement a few months after it was put in. Had it not been discovered in time, something similar to if not worse than the Hartford disaster would have followed. We also know of other buildings in New York whose boilers, although they will be pronounced safe by the ordinary inspector, are such that we are free to say that we would not take offices over them.

"With the advance of civilization and the increasing wants of our people, boilers are being multiplied to an enormous extent; and such multiplication must necessarily increase the number of explosions and casualties unless additional care is taken in the construction, inspection, and management of boilers. We do not wish to appear to advocate any special type of boilers; but, in view of the above facts and dangers which they indicate, we think it is about time that some legislative action was taken to prevent the use of shell boilers within the walls of a building occupied either as a residence, an office building, or a hotel.

"Water-tube or other sectional boilers, whatever other disadvantages they may have, have this in their favor, that with them a general explosion can hardly take place. They may rupture a header or burst a tube, and perhaps kill or scald a fireman, should he be very near at the time; but the destruction of a building would be practically impossible by any accident that is likely to befall them."

* *Sanitary Engineer and Building Record*, March 2, 1889.

A writer in the *London Mechanics' Magazine* says: "It is not too much to say that nine out of ten explosions are directly the result of corrosion. Setting aside the value of human life and limb, we find that the mere pecuniary interests involved in either the gradual or sudden destruction of a boiler are very considerable.

"Repairs are at all times expensive, and the time lost in making them is often a source of pecuniary loss, worry, and trouble. Hence the replacement of a plate, or the alteration of a defective flue, is often staved off from day to day, until irreparable mischief is done.

"Reflecting on these things, it seems strange that boilers are made, fired, and worked with negligence, which apparently regards iron plates as indestructible, and the results of an explosion trifling to a degree.

"We cannot set such a system, or rather such a want of system, down wholly to stupidity or neglect.

"We know that boilers in the best hands, and under the most careful management, often become worthless with startling rapidity, which no amount of theoretical reasoning will account for, nor practical skill arrest or delay.

"The utter uncertainty in which the engineer is doomed to live, as to what does or does not promote durability, leads naturally to recklessness, neither the result of the want of thought nor of indolence.

"Corrosion is too often regarded in the light of fate—a destroyer, merciless and indiscriminate, before which, as a *fetish*, the manufacturer and the ship owner bow down and submit."

BOILER EXPLOSIONS IN ENGLAND IN 1886.

The Annual Report of Mr. Henry Hiller, Chief Engineer of the National Boiler Insurance Company, Manchester, Eng., is at hand, and from it we extract the following relating to boiler explosions in the United Kingdom during the past year:—

There were reported during the past year 32 actual explosions of steam boilers, causing the death of 30 persons and severe injury to 57 others. In 1885 36 explosions caused the death of 30 persons and injury to 57—exactly the same number as the past year. In the five years ending Dec. 31, 1870, there were 282 explosions, causing 358 *deaths*, or an average per annum of 56.4 explosions and 71.6 deaths; against an average per annum for a similar period ending Dec. 31, 1885, of 37 explosions and 30 deaths—a decrease, compared with the above, of 34.4 per cent in the number of explosions and 58.1 per cent in the number of deaths.

Mr. Hiller justly observes that this reduction is doubtless due in a great measure to the efficient service rendered by the boiler insurance companies, and adds that the average could be much further reduced if the advice given by the inspectors were always heeded by the owners of the boilers.

Of the 32 explosions reported, the largest number, 19, occurred from defective condition of the boilers; 5 arose from mistake, negligence, or mismanagement; 5 from defects due to mal-construction or original weakness; and 3 from other causes. The explosions of vertical boilers with internal fire boxes head the list, being 8, or one fourth of the total of the year.

If a boiler insurance inspector or insurance company could prescribe the daily handling and care of their boilers, then the risks might be lessened, if not eliminated. But this does not seem possible. The owner not being a practical man sees none of the real and vital requirements, and, if he did, is continually diverted from them by considerations of first cost, and his weekly bills.

Cheap help is to him a name for economy — he does not stop to consider how much may be lost at his fuel pile from imperfect combustion, or at the steam pipe by imperfectly set engine valves, or the undue friction of moving and imperfectly lubricated machinery.

No insurance policies can give a safe boiler construction, or employ competent men to run and care for them.

*** Explanation of Boiler Explosions.** Would we know *why* boilers explode? Peter has told us all about it.

"There are two kinds of steam in the boiler when it is at work; viz., engine driving steam, which is one-third water, and explosive steam.

"Explosive steam may be of a variety of colors — blue, red, mottled, and, in fact, anything else almost; it all depends on the color of the end of one's nose how he looks at it. It is also liable to get dry and 'grippy' — whatever that is. As long as you can keep the two different kinds of steam well mixed, there is no danger of an explosion, no chance for the red, white, and blue explosive steam to get 'grippy;' but just let them get separated, let the explosive steam get into a layer by itself down next to the water, where hot spray can 'spatter' up into it, and off she goes! Just exactly two thousand pounds to the square inch will be generated under these circumstances every time, and don't you forget it, for Peter says so; and he has run a boiler this way two years, and it did n't explode either, and he run it all the time with low water, and you can't explode a boiler unless it has low water; they only burst when they have water enough in them, and he has examined seven thousand four hundred and eighty-four cases, and only one burst, and that had on one hundred and seventy pounds; and you need n't blow up then if you'll keep blowing off; a boiler will explode just as quick with ten pounds as it will with three hundred and fifty pounds, and every boiler explosion is just the same way. This is what Peter says, and is a fair sample of what may be heard in many of the boiler-rooms where *Peters* and the shell boiler are in service together.

"The explosion which probably caused the greatest loss of life on record occurred on the Mississippi River near Memphis, Tenn., on the 26th of April, 1865. The steamer Sultana was on her way up the river with about two thousand two hundred people on board, mostly Union soldiers just liberated from Southern prisons. When near Memphis her boiler exploded, destroying the boat, and one th[illegible]sand seven hundred lives were lost. Many were instantly killed and the others [illegible]ed, being two weak, from their experience in prisons of the South, to do an[illegible] to save themselves."

* *The Locomotiv[illegible]*

*PREVENTION OF BOILER EXPLOSIONS.

"The recent steam-boiler explosion warns us again, in tones not soon to be forgotten, that greater security to life and property in the use of steam has become a paramount necessity; and, leaving out all other considerations, the subject demands the earnest attention of every one who values his own personal safety. The public will be again told that ignorance and want of experience, reckless if not wilful neglect of the most obvious precautions, material and workmanship of bad quality, low water, over-pressure, explosive gases, electricity, or some other thing has been the cause of this terrible calamity.

"But it must not be overlooked that steam-boiler explosions, largely destructive to life and property, have occurred more than once in the largest, most experienced, and most carefully managed engineering and manufacturing establishments in the city.

"And it must also be borne in mind that it is quite impossible to procure boiler plates of wrought iron invariably reliable, or that will remain so, no matter how much care is bestowed on their manufacture and inspection. It is also equally certain that the best material ever put together, with the very best workmanship, under the present system, may and does frequently share the fate of the most inferior. Thus, whether these much-used appliances are made as near perfection as may be, directed by intelligent and skillful management, or the reverse, the end is too often the same. Under such a condition of things it is not worth while to waste time in theorizing as to questionable causes. It is with the disastrous results and their possible remedies that wise men should deal.

"Steam boilers can be no more made absolutely secure against some kind of explosion and fracture than guns or ordnance. But they should be and can be made so that no serious harm may arise when they do give way. To accomplish this most important end, the prevailing system has been found, after a century of trial, entirely at fault, and improvements must be looked for in its abandonment.

"Councils, if they have the power, or, if they have not, then the State Legislature, in their effort to enforce stringent laws for the inspection of boilers of the kind that are known to be liable to disastrous explosions, should try the experiment of an ordinance or law that no boilers, after a certain date, shall be erected within our city limits, unless a certificate is first obtained from competent inspectors that an explosion of said boiler would not be dangerous. There is no full security in any direction, pass what law you will, make what inspection you may.

"The time is not far distant when the present system must come to an end, unless it can be proved beyond all doubt that no change for the better is possible. The public safety now demands that these engines of destruction shall no longer be kept hidden from sight in the basements of our most densely peopled neighborhoods, or in our crowded workshops, and even under the busy footways over which we unconsciously tread, always ready for havoc, and only perhaps temporarily held from repeating the horrors of last Thursday by a constantly weakening chain, the real strength of which is seldom if ever known.

"If these destructive engines were new things, and it was now first proposed to place hundreds of them in our crowded thoroughfares and under our pavements, who would listen to such a proposition? It would not be entertained for a moment. Neither should the system itself, although it is well established, be tolerated a day beyond the time when it can be dispensed with.

"It is beyond controversy or doubt that the fracture of steam-generating apparatus can and may occur under any system of construction. No amount of official inspection or special care can entirely prevent this; and it must be set down as an imperative law, if safety is to be secured, '*that all boilers should be so constructed that their explosions should not be dangerous.*'"

*Joseph Harrison, 1867.

In the matter of boiler insurance and inspection, the writer, while approving and urging insurance and inspection in *explosive* and *shell* boilers, desires to call the attention of these companies and engineers to the hydrostatic or cold-water test, and to the probability that great harm may be done in an *injudicious application of the proving pump.*

While the water test applied to a shell boiler at one hundred or one hundred and twenty-five pounds pressure will generally develop any small leaks or weakness at the seams, rivets, or tube ends, it really conveys no other information, or demonstrates that a boiler is fit to carry as much steam pressure.

Many engineers who have given the pump test careful consideration are of the opinion that it is of doubtful utility, and liable to strain and injure a boiler, while apparently looking for its weakness.

The writer once nearly paid the penalty of his life by trusting to a pump test of a piece of cast-boiler construction.

The casting was substantially 24 x 30 x 6 inches, and strengthened, in the usual way, by stays between the two flat sides. There was about six inches space, as is seen in the construction of the locomotive fire box. As this was intended for a water back to a power, sectional, Mills boiler, it was proved under the pump to *one hundred and twenty pounds*, but afterwards exploded at *eighty-five* pounds steam pressure. The accident injured three men, but all recovered.

Examination by an expert developed the fact, that most of the internal stays had been broken, torn from the sides by the forcing pump — the proof being that the ends of the stays were black and rusted, *showing rupture before the explosion*, the final breakage showing bright, and a proper thickness of the iron.

As far as sectional boilers are concerned, there seems to be no special advantage in outside inspection, or to enact the farce of insuring a boiler against explosion that is practically non-explosive, and where none of the conditions are present to meet which the insurance companies are organized, and for which they train their men to search.

For instance, there is no shell to pump up, to probe and rap with a hammer, or on which to deposit the sediment of long evaporation. There are neither heads to hold in place with stays, nor rivets on which both the stays and heads depend; while the tubes, the only other part that the average boiler inspector would recognize, are no longer in the condition he has been accustomed to find them; and, when he comes about a boiler of this kind, his inspection is necessarily limited to the location and general surroundings. Most of the fittings are also out of the range of his general experience; and, if he attempts to apply to them his regular list of special instructions, the result is not likely to be beneficial either to the boiler inspected or to the party that pays for it.

As applied to cast-metal construction, and those mainly employed for the distribution of heat, there seems less reason or use for a line of inspection and test prescribed for other constructions and conditions.

In heating apparatus of either the steam or water variety, great tensile strength is not primarily sought, neither demanded; the low-pressure steam boiler is generally operated under fifteen pounds gauge pressure, while the hot-water circulations do not often exceed this pressure unless the height of the building requires a higher water column to serve the upper stories.

It is clearly for the interest of insurance companies to have built, equipped, and sold machines which afford them a living, as, if these shells were not explosive, their occupations would be gone. So, by the testimony and influence of the seemingly disinterested class of engineers, — men who for years have been educated in the details of this construction, — if this form and type of boiler were abolished, their occupation would be gone, and they would have to learn a new trade.

Thus we see briefly what are the bonds that bind this unruly demon to the back of unsuspecting and suffering humanity.

While intending to say nothing to weaken or disparage the effort of inspectors and insurance of the *wrought-iron or steel shell boilers*, it may be well, and in the interest of both parties — the owner and the insurer — to ask both a simple question: Against what do inspection and insurance really insure? Against the final catastrophe of explosion? Oh, no! It only reduces the chances of it, and provides a money indemnity for the victims.

It does not abolish explosions of shell boilers any more than life insurance *abolishes death*. And the singular reflection comes home to the thinking mortal, that he must first die to secure a policy on his life, and go through "sheol" to get one on an exploded boiler.

What satisfaction was it to the proprietor of the Park Central Hotel that "the boiler was insured, and that the certificate hung in the engine room?"

One other view of this matter may not be passed over here, although it will be treated more fully in its regular order; that is,

Safety in the heating boiler is determined fully as much by the method, as by the machines employed.

A water medium for absorbing and circulating the heat dispenses with the steam altogether, and with the danger and complications attending its generation and use.

But here, again, the same general reasons prevail for using steam as a heating agent as we have seen brought to bear on the production and use of the steam boiler — so many more people make the steam boiler, and so many more understand no other method of generating and circulating heat.

SOME IMPROVED WROUGHT-IRON BOILERS.

Since the great majority of boilers are of the shell and tubular variety, and as these in some form will continue to be used both for power and heating purposes, we will glance briefly at a few examples *of improved construction, which have, by a departure from the common and older forms, secured a further degree of economy and safety.*

The reference and approval of these wrought-iron boilers shown are for two reasons: First, to neutralize seemingly undue criticisms of wrought-iron and shell boilers as a class; and second because in these boilers are elements of *safety*, *economy*, and *efficiency* not found in common constructions.

From nothing does the tubular boiler suffer more than from the setting, and the unequal expansion produced by the unequal heat.

If the heat reached all parts of the boiler alike, it would wear alike, the shell lasting as long as the tubes. That this is not so, is shown in the shell giving out first, a set of tubes often enduring to do duty in two boilers. It is the lower plate of the shell that suffers the most and that gives out first.

As we remarked, this is largely due to the setting; since the common return tubular may be so set as to reverse the old-time and poor application of the heat. The direction in which the fire is applied and in which the heat leaves the absorbing surfaces has everything to do with the economy secured.

It was a consideration of such facts which led to the invention and construction of the Lowe boiler, where the fire and gases, before becoming cooled and expanded, entered the *tubes first, and returned under the shell last.* This is working the heat in the right direction, and should certainly result in economy and dry steam.

1st. In the Lowe boiler may be seen a clear comprehension and working out of safety elements, a grate surface, fire, and combustion chamber, that cannot but yield valuable and economical results.

2d. The reversal of the common practice of firing under the shell and up through the tubes by firing through the tubes, and *downwards under the shell*, discharging the gases at that point, or up and around the steam drum as shown in the cut at D. L. F.

3d. The recognition and provision for a separate steam and storage chamber, and, when desired, a corresponding feed and mud drum, *below the boiler*, on which the spent and lowered gases do useful work.

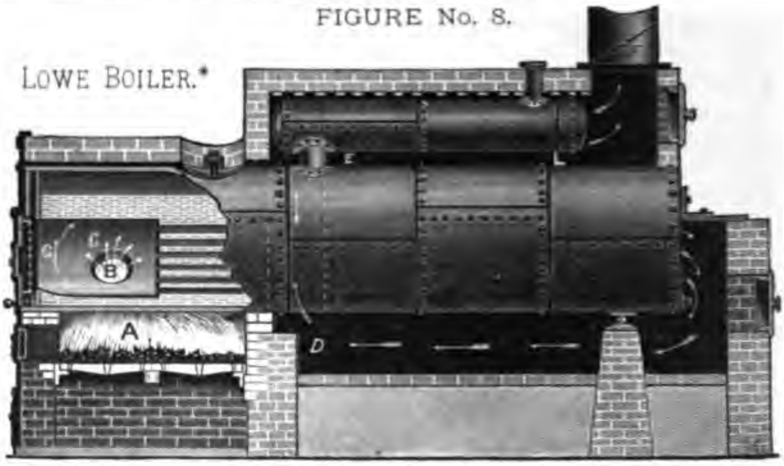
These three distinctive and valuable features should alone be sufficient to challenge the attention and approval of all practical engineer

As before remarked, we believe that in this entirely simple construction — rather reconstruction of the setting of the wrought-iron return tubular boiler — are embodied more valuable features than in any known to the writer.

That this application and run of the fire, first through the tubes and under the shell, is attracting the attention of engineers, is seen in what is called the Electric Furnace. (St. Louis, Mo.)

FIGURE No. 8.

LOWE BOILER.*



In the cut we see the regular fire chamber at A extending back only the usual length to grates. The combustion chamber proper is in the front end of the shell at CC, the products of combustion entering from below at orifice B; while either hot or cold air to mix with the gases may be admitted through the perforated plates and registers seen in front; the gases, then properly supplied with oxygen, enter the tubes, and, on their exit at the rear end, ***pass downward and under the shell, as shown, finding exit at*** D.

That there are virtue and economy in a forced over a chimney draught is clear; also that a blower sending hot air to the ash pit and the combustion chamber of the Lowe boiler would produce surprising results; while the whole change of construction and the mixing of the furnace gas in proper combustion chambers is only carrying out the principle laid down by chemists and scientific engineers, and illustrated in the diagrams of combustion, Part I., pages 70 to 90; also chapter on furnace construction, pages 93 to 106. The subject of the *draught* being all imperative, the testimony of practical engineers, with the details of experiment, is admitted as proof of the opinion offered, and as showing that here is one of the economies often overlooked or credited to other conditions. See "Hoadley Experiments," page 266.

*BRIDGEPORT (CONN.) BOILER WORKS, WM. LOWE, PROPRIETOR.

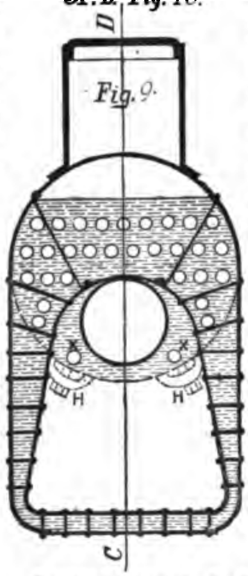
THE NEW "ECONOMIZER." PORTABLE BOILER.*

This horizontal boiler of the locomotive fire-box type has several valuable features readily distinguished by engineers; but we may point them out briefly, seeing that this class of boilers is still a favorite with some heating firms, even when arranging for a water circulation.

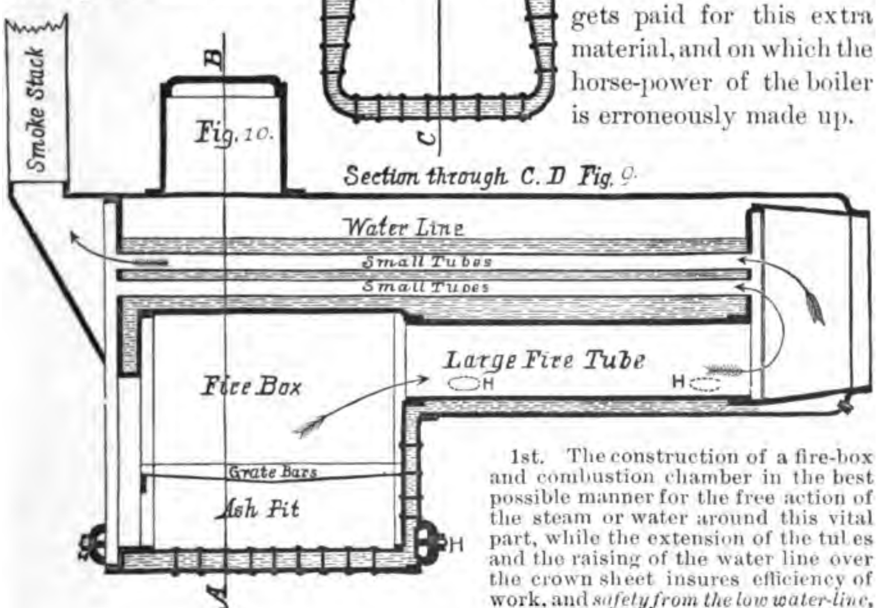
The single central tube throws light on the common but fallacious idea that the fitting of the whole tube sheet of horizontal boilers with tubes of small diameter is an essential element of power and efficiency; the proportion of tube area to the grate is by far the best factor. In this case the proportions are, say, grate, 900 square inches; exit flue, 150 inches, or about one sixth of the grate area.

In common horizontal boilers having the same grate area, it is common to see for steam and for water circulation thirty to forty two and one-half or three-inch tubes, say 200 inches of tube area, or one quarter more area than the furnace gases will fill when under strong draught; and when under moderate draught, 50 per cent more exit than the gases require to do their best work. Probably one quarter of the tubes in horizontal boilers are a dead loss to all except the manufacturer, who gets paid for this extra material, and on which the horse-power of the boiler is erroneously made up.

Section through A.B. Fig. 10.



Section through C.D Fig. 9.



1st. The construction of a fire-box and combustion chamber in the best possible manner for the free action of the steam or water around this vital part, while the extension of the tubes and the raising of the water line over the crown sheet insures efficiency of work, and *safety from the low water-line, a trouble common in this class of boilers.*

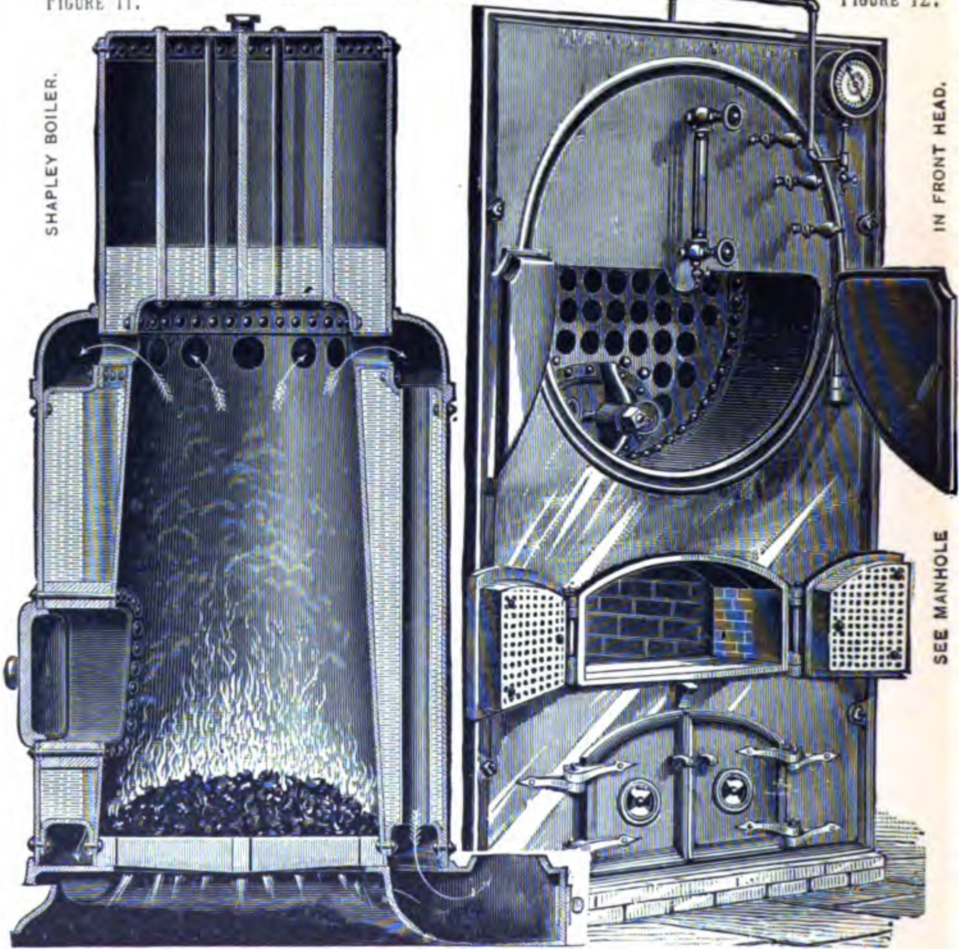
2d. Passing the products of combustion out of the fire chamber by a single large tube, instead of through many small ones, is another good construction to which may be referred much of the economy obtained.

*** The new Economizer Boiler, S. L. HOLT & Co., Agents, No. 67 Sudbury Street, Boston, Mass.**

* The Shapley, another representative boiler, is also given room and illustration, since of the regular vertical class of shell boilers but little good has been said or carried to their credit, owing, doubtless, to the difficulty of securing a change of unfavorable conditions of tubes and flues and steam surfaces.

Wrought-iron *vertical* boilers usually are wasteful of fuel, because of the conditions already stated. Those of the regular wrought-iron vertical tubes, discharging the products of combustion from a smoke bonnet *at the top*, will not evaporate more than two thirds of the water from the same amount of coal as the *horizontal* return tubular.

FIGURE 11. * THE BIGELOW COMPANY, NEW HAVEN, CONN. FIGURE 12.



Briefly, the advantages of this boiler are: Its large, roomy combustion chamber, and *downwards escape of the products of combustion*, by which a greater economy of fuel is secured. I do not know if any evaporative tests have been made of the Shapley boiler, but I will venture that here will be found the highest duty obtainable from any boiler of wrought-iron vertical construction.

The large steam dome, submerged tube sheet, and efficient water surfaces render it the admiration of mechanics and engineers.

RECAPITULATION AND COROLLARY.

All steam boilers may be ruptured if not exploded (a) by faulty construction; (b) by imperfect care and bad management.

BUT ALL STEAM BOILERS MAY BE SO CONSTRUCTED THAT THEIR EXPLOSIONS AND RUPTURES, FROM WHATEVER CAUSE, SHALL NOT BE DANGEROUS TO HUMAN LIFE.

The *shell* of wrought-iron and steel boilers is the dangerous feature, as in them is stored the quantity of force which, released by rupture of the weakest part, carries destruction in every direction. A barrel of gunpowder in bulk might do an equal damage; but, *subdivided* into small parcels, may be exploded for our amusement, as in Chinese fire crackers and other 4th of July entertainments.

Sectional boilers are safe from disastrous explosion because the water and steam under pressure are subdivided into small compartments of great strength. The rupture of one of them releases the pressure, without exploding the others. The breakage can be repaired at small expense.

Security, then, against sudden and disastrous rupture can only be found by dispensing with the large shell and arranging the tubes to do the work.

This has been found entirely practicable, and is exemplified in what we know to-day as the sectional or safety boiler, a large number of which are manufactured, and employed in every variety of work.

Steam-boiler inspection by insurance companies lessens the chances of accident, explosion, and death from unsafe boilers, but it can only mitigate an evil *inherent in the construction and mismanagement all such boilers are liable to.*

Faulty construction, materials, and bad treatment being the rule rather than the exception, safety may be only looked for in a sectional construction, where explosion is practically impossible.

If you have a shell boiler, insure it by all means; but don't expect too much of the company's inspectors, or that such inspection and insurance will relieve you from doing all in your power to second their efforts.

1st. *By employing only competent and reliable men as engineers and firemen, who will coöperate with the inspectors and yourself in securing safety and economy in this difficult and hazardous occupation.*

2d. *Don't object to pay the policy or tax for the inspection or a fair and even liberal compensation to men who are worthy of such positions of trust and responsibility. The engineer is worthy of his hire.*

SUMMARY OF BOILER EXPLOSIONS FOR THE YEAR 1887.*

"Our usual summary and classified list of boiler explosions is given below. The total number of explosions, so far as we have been enabled to learn, was 198. In many cases more than one boiler exploded, but it is reported as one explosion.

"The number of persons instantly killed, or so badly injured that they died within a very short time after the accident, was 264 ; the number injured, many of whom were stated by the reports to be fatally injured, was 388, or a grand total of 652 persons killed and badly hurt. This is a showing of which the people of the country at large are not, in all probability, at all proud. The figures in detail are given in the accompanying table.

"The explosions of the past year do not appear to have been more than usually destructive, or to have killed or injured more than the usual number of people. The whole number reported killed foots up 264, against 254 in 1886, while the injured are 388 compared with 314 the previous year, the increase being in about the same ratio that the number of explosions reported have increased.

CLASSIFIED LIST OF BOILER EXPLOSIONS IN THE YEAR 1887.

CLASS OF BOILER.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total per Class.
1. Saw-mills and other Wood-working establishments . . .	7	4	6	6	8	6	2	3	5	9	13	4	73
2. Locomotives	1	2	1	..	2	1	1	..	1	1	2	2	14
3. Steamships, Tugs, and other steam vessels	2	..	..	2	3	..	..	1	1	4	..	1	14
4. Portable Boilers, Hoisters, and Agricultural Engines . . .	2	..	..	..	1	3	5	2	1	1	3	2	20
5. Mines, Oil Wells, Collieries . .	3	3	..	1	1	2	1	1	..	..	..	1	13
6. Paper Mills, Bleacheries, Digesters, etc.	2	1	..	1	1	..	..	..	..	..	..	..	5
7. Rolling Mills and Iron Works .	3	1	..	1	..	..	1	2	1	2	2	2	15
8. Distilleries, Breweries, Dye-works, Sugar Houses, etc.	1	..	1	1	..	1	2	..	1	..	2	..	9
9. Flour Mills and Grain Elevators .	2	..	..	2	1	..	..	..	1	1	..	..	7
10. Textile Manufactories . . .	..	..	..	..	1	..	..	..	..	..	..	..	1
11. Miscellaneous	3	1	..	3	..	1	2	1	3	3	6	4	27
Total per month, ...	26	12	8	17	18	14	14	10	14	21	28	16	198
Persons killed, total, 264 } 652	27	6	7	14	25	15	15	7	11	71	40	26	
Persons injured, total, 388 }	.31	17	23	43	39	41	20	19	19	65	53	18	

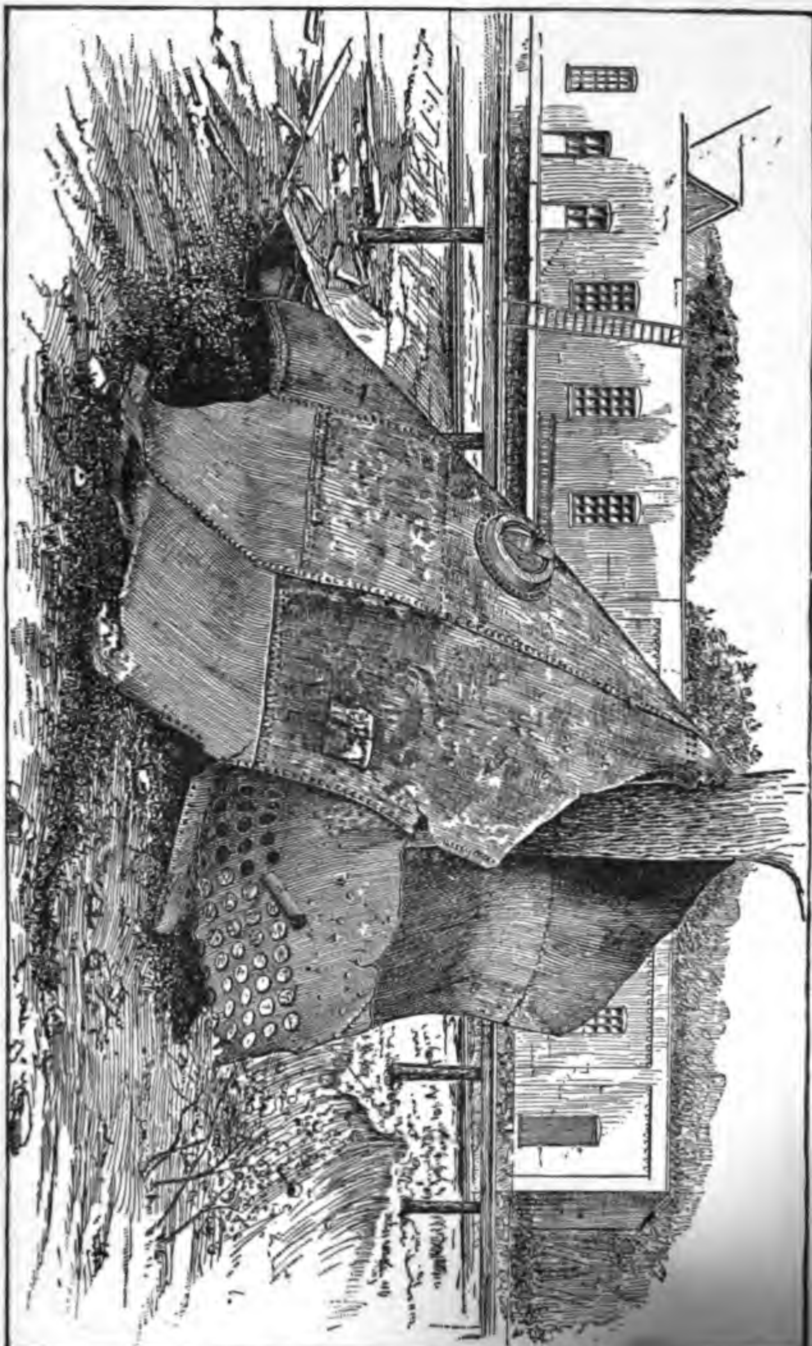
"Nearly 37 per cent of the whole number of explosions were, as usual, furnished by the lively saw-mill boiler. Portable boilers, hoisters, agricultural boilers, come next, but their number was but little more than one fourth of those occurring in saw-mills. Rolling-mills come next with fifteen, while locomotives and steam vessels are tied for fourth place. The other classes furnish about the usual number of explosions.

† "*During the six years ending Jan.* 1, 1886, *there were* 992 *boiler explosions in this country, by which more than* 1,500 *persons were killed, and many more injured. A large amount of property was destroyed and damaged, besides the loss resulting from delays in rebuilding and replacing boilers and machinery destroyed or rendered useless. These figures are taken from a record which has been kept for many years in the office of the company with which I am connected. They are gathered through our agents in all parts of the country, also from the daily papers.*"

* *Locomotive*, February, 1888.   † J. M. ALLEN, in *Locomotive*, September, 1888.

PLATE No. 7.

RESULTS FOR THE YEAR 1888 { **FOR SHELL BOILERS, KILLED AND MAIMED, 836.**
FOR SECTIONAL BOILERS, 0.



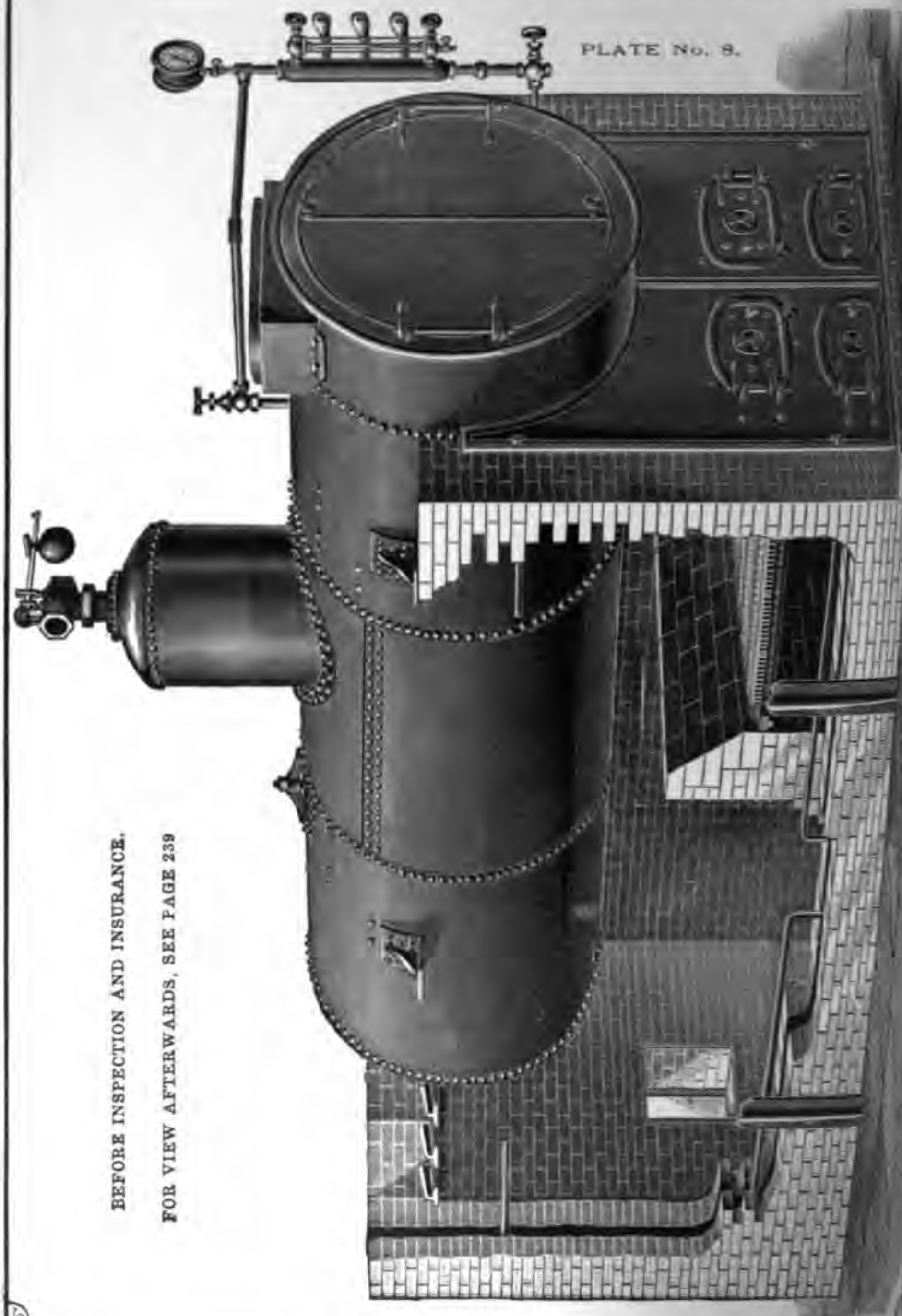
TUBULAR BOILER, LATE OF THE "SUPERIOR MILLS," YPSILANT, MICH., 1888.
AFTER "INSPECTION AND INSURANCE."

Dimensions:—72 inches diameter by 16 feet long; 3-8 in. shell plates, double riveted 7-16 in. heads.
BUILT BY BUHL IRON WORKS, DETROIT, MICH.

From the Hartford Boiler Insurance Reports, 18

THE "REGULAR" WROUGHT-IRON RETURN TUBULAR BOILER.

PLATE No. 8.



BEFORE INSPECTION AND INSURANCE.

FOR VIEW AFTERWARDS, SEE PAGE 239

CHAPTER XV.

SAFETY SECTIONAL POWER BOILERS.

ON this broad subject, the sectional and safety versus the shell and explosive boilers, it seems desirable to make a division into two classes — those designed for the production of high pressure, steam, or power, and those not aiming at this directly, but intended for the generation of steam at a lower pressure, or the absorbing of heat into a water medium for purposes of distribution.

It will be noticed that at the beginning of this subject we divided the boilers into three classes — safety boilers, steam generators, and heaters; it may now be plain that there should have been a fourth class, the "unsafe boilers."

The distinction between "safety boilers" and steam generators may not be clearly apparent unless we draw the line between certain forms of safety construction primarily designed to furnish steam of high pressure for power purposes, and certain other constructions, generally of cast metal. These last, while being amply strong and reliable for high pressure, are not put upon the market with that view, but rather to carry the lower pressure required in warming operations.

Of the safety boilers, we must be contented with a review and illustration of one from each distinctive class, intending, as usual, that they shall be the best examples, and cover the principles sought in others of like merit.

The most prominent and successful of these are the Abendroth & Root, the Babcock & Wilcox, and the Heine Boiler, the latter being employed by the Boston Heating Company for their water circulation, and to carry pressure of one hundred and fifty to two hundred pounds to the square inch.

There is not a great difference in the principle and construction of inclined tube safety boilers, and a single illustration will suffice. The cut on page 247 shows the Abendroth & Root construction, with the *improved mechanical Brightman furnace*, all this class of inclined tubular boilers being admirably adapted to this construction of grate, requiring elevation at the front end and a roomy combustion chamber.

The latest work on boiler subjects is "Thurston's Manual" (J. Wiley, New York, 1888), a clear, comprehensive, and practical treatise of some 400 pages, and from which we quote pages 7, 38, 148, and 314 — the author having in mind and referring mainly to wrought and steel tube construction of sectional boilers, as exemplified in the Root, Babcock & Wilcox, and other inclined tube construction.

Thurston says: "Special purposes produce the modern types of boilers. Thus, a desire to secure maximum efficiency produced the tubular boilers, and a desire to *secure safety* the so-called '*sectional boilers.*' *As early as* 1793 *Barlow invented and, with Fulton, used the 'water-tube' boiler*, in which the water circulates *through the tubes* instead of around them, as in 'fire-tube' boilers. This was the pioneer of a great many boilers of this class.

"John Stevens, a distinguished statesman as well as an engineer, in the early part of the nineteenth century (1804), devised another example of this class. The inventor says in his specifications: 'The principle of this invention consists in forming a boiler by means of a combination of small vessels instead of using, as in the common mode, one large one — the relative strength of the materials of which these boilers are composed increasing in proportion to the diminution in capacity.'

"*The relative strength of shell and sectional boilers*, and consequently, in large degree, their relative safety '*is measured by the relative magnitude of their largest parts.*'"

As remarked by *John Stevens the inventor* (1804), the sectional boiler, with its smaller members and subdivided steam and water chambers, is safe in proportion as the sizes of the latter are diminished; while the large shell of the common forms of boiler are liable to dangerous rupture in proportion as their diameters are increased. The strengths of cylindrical reservoirs subjected to internal pressure, as are shells, steam drums, and mud drums of shell boilers, and the tubes and steam reservoirs of sectional boilers, are subject to laws so simple, and are computed by methods of such easy application, that there never need be any doubt in regard to the margin of safety existing in either case when new. *Flues and old boiler shells are less amenable to calculation, and are thus more unsafe. Water tubular boilers are comparatively safe under all conditions of ordinary operation, and, when compared with any other type of steam generator, are vastly safer.*

Page 314. "*Shell and sectional boilers*, compared in other respects than in reference to safety, in which attributes the latter are specially constructed to excel, are found, when equally well designed and constructed, and equally well managed, to stand on substantially the same level.

"The two types of boiler in most common use are the *water-tube sectional* and the cylindrical fire-tube (shell) boiler.

"The former of these two classes has the *grand advantage of safety against disruptive, disastrous explosions, has equally good or better circulation and general efficiency, less weight and volume for equal powers, and greater reliability in its details of structure.* It is rapidly coming into favor among engineers and into use as well.

"The author would often use the shell boiler, where commercial reasons would dictate such use, and, wherever practicable, would select the externally fired, cylindrical fire-tube boiler; *but would never place a shell boiler under a building in which its explosion would endanger life or property. The safety class of boilers would be the only kind found to be wisely adopted in such locations. Shell boilers should usually be placed in detached boiler-houses, and so set, as to position, that danger shall be made a minimum.*"

No plainer or more impartial statement of actual conditions and no clearer deductions have been placed on record by any competent writers, certainly not by any disinterested engineer. The fact of such reviews and expressions of conviction from an engineer, educated under the old and accepted order of shell boilers, is a point to be noted as marking a growing change of sentiment, both as regards those who have labored to introduce sectional boilers in the past, and certainly as favoring the improved and more perfect steam generators of the present.

THE ROOT SECTIONAL STEEL WATER-TUBE BOILERS.*

The essential features to which this boiler owes its entire safety from explosion are the small diameters of its parts, or, in other words, the subdivision of the water and steam into small compartments; and it needs no argument to show the superiority, in point of strength, of small over large diameters.

It is a well-known practical fact that boiler *tubes* do not explode, as is the case in the shells of boilers; but that excessive pressure (many times greater than a shell will bear) merely causes a rupture of greater or less extent, and thus relieves the pressure without serious damage.

Each of these tubes, containing but a small amount of water or steam, might be ruptured without serious results, thus relieving the boiler and preventing disaster.

The first form of boilers, the *plain cylinder*, being very uneconomical in fuel, and occupying the greatest space per horse-power, has been, in a measure, superseded by the flue boiler, and this, still uneconomical, by the *tubular boiler*, in its many varieties. The use of *tubes* without the shell greatly reduces the space occupied, and, by subdividing the water and introducing a large amount of heating surface composed of thin iron tubes, accomplishes another very valuable result, economy of fuel.

It is this shell, containing the whole volume of the water and steam, that always, or nearly always, explodes, and usually results in fearful havoc.

It is the shell and fire box of the ordinary tubular boiler that require frequent patching, these repairs constantly weakening the remaining portion of the sheets (as it is well established that a single riveted joint has but 50 per cent of the strength of the plate before punching and riveting, and this with the best workmanship). This shows that the tubes are the most durable part of the boiler; and the only damage they suffer is due to irregularity of expansion and contraction, which fault is here avoided.

Boilers made with shells may bear a high degree of cold-water pressure when all the parts remain at one temperature; but the application of heat on one side may produce such an immense strain, by inequality of expansion, as to nearly break up the boiler without steam pressure.

This explains why some new boilers burst at first firing, after having borne the cold-water test. The parts of safety boilers being uniform in length and size, will expand and contract nearly equally; or, if any inequality of expansion should occur, it would have no bad effect, owing to the manner of attaching the parts together. See page 246.

This uniformity of parts in all the sizes renders the largest boilers as strong as the smallest, which is not the case in the ordinary forms.

Scale and Sediment. As this matter of scale and sediment is the greatest difficulty met in steam engineering, and more loss, trouble, and danger occur from this cause than any other, the point of superiority of this boiler should be thoroughly understood.

The ease with which this boiler can be thoroughly cleaned, if through neglect it becomes incrusted, is evident; and, if through such negligence damage should be done to any part, it can be renewed with a trifling expense of time and money; and such want of care, which is the cause of many boiler explosions, with loss of life and property, in this boiler can cause but slight damage in some of its parts. It may get red-hot, or burn out, so that some of the tubes will leak or require replacing, but it will not explode.

In a large shell, say five feet in diameter, which is a common size, if it becomes weakened by burning (or other causes) in any part, the internal surface on which the pressure of the steam or water is exerted, is so great, that it is immediately burst open at the weakened point, and rips or tears from that point in any direction like a piece of cloth, and the whole expansive power of the heated water and steam is immediately liberated, dealing destruction around.

In a tube of four inches diameter the result is different. Its strength to resist internal pressure is, in the first place, from *ten to twenty times* that of the five-feet shell; and, then again, if burned entirely through at any point, its strength is so great in proportion to the internal surface exposed to pressure, that no such thing as an explosion or tearing to pieces can occur. A mere leak occurs, and the boiler may be used with safety for weeks after, or until the leakage is so great as to stop the use of the boiler. No such thing as the burning out of a tube can take place, however, except for the want of water or its being filled with sediment; in either case the result of great carelessness and neglect.

The following are the prominent advantages that these boilers present over those of the ordinary shell construction: —

1. **The Transmission of Heat.** The thick plates necessarily used in ordinary boilers, in the furnace, or immediately exposed to the fire, not only hinder the free transmission of heat to the water, but admit of overheating. Water tubes, however, admit of thin envelopes for the water next the fire, with such ready transmission of heat that not even the fiercest fire can overheat or injure the surface, as long as it is covered with water on the other side.

2. **Joints Removed from the Fire.** Riveted joints, with their consequent double thickness of metal in parts exposed to the fire, give rise to serious difficulties. Being the weakest parts of the structure, they concentrate upon themselves all strains of unequal expansion, giving rise to frequent leaks and not infrequently to actual rupture. These difficulties are wholly overcome by the use of lap-welded water tubes, with their joints removed from the fire. The joints between tubes and tube sheets also give much trouble when exposed to the direct fire.

3. **Thorough Absorption of Heat.** There are important advantages gained in this respect, in consequence of the course of the gases being more nearly at right angles to the heating surface impinging thereon, instead of gliding by in parallel lines, as in the case of fire-tube boilers. The current passing across and between the staggered tubes is brought more intimately in contact with all parts of the heating surface, rendering it much more efficient than the same surface of ordinary tubular boilers. The experiments of Dr. Alban and of the United States Navy have proved that a given surface arranged in this manner is 30 per cent more efficacious than when fire tubes are used.

4. **Efficient Circulation of Water.** All the water in the boiler tends to circulate in one direction; there are no interfering currents, and the steam is carried off quickly from the surface; all parts of the boiler are kept at nearly equal temperature, preventing unequal strains; and by the rapid, sweeping current the tendency to deposit sediment on the heating surface is materially lessened.

5. **Dryness of Steam.** The large disengaging surface of the water in the drum, together with the fact that the steam is delivered at one end and taken out of the other, secures a thorough separation of the steam from the water, even when the boiler is forced to its utmost. The large area of surface at the water line and the ample passages for circulation secure a steadiness of level not surpassed in any boiler.

6. **Freedom of Expansion.** The triangular arrangement of the parts forming a flexible structure allows any member to expand without straining any other, the expanding sections being also amply elastic to meet all necessities of this kind.

7. **Accessibility for Cleaning.** This is of the greatest importance, and is secured to the fullest extent. Hand holes with metal joints, opposite each end of a tube, permit access thereto for cleaning, and a man hole in the steam and water drum and hand holes in mud drum are provided for the same purpose.

8. **Durability.** Besides the important increase in durability, due to the absence of deteriorating strains, and of thick plates and joints on the fire, there is no portion of the boiler exposed to the abraxive action that so quickly destroys the ends of fire tubes, or to the blow-pipe action of the flame on the crown sheet, bridge walls, and tube sheets, which are so destructive frequently to ordinary boilers.

NOTE.—Of the efficiency really secured, we have, as stated, no detailed or later evidence than that of the Centennial experiments, which are, as seen by the accompanying table, the highest of all reliable records from 1874 to 1887. See table No. 7, page 265.

We have gone somewhat at length into the description and claims of the Root safety boiler, because the subject is an important one, and because the description and distinctions drawn are applicable to other tubular constructions made without a shell, whether vertical or horizontal, and whether made of wrought or cast iron; and thus we shall not continue the parallel when referring to the Harrison, the Exeter, Gold, or the Mills boilers.

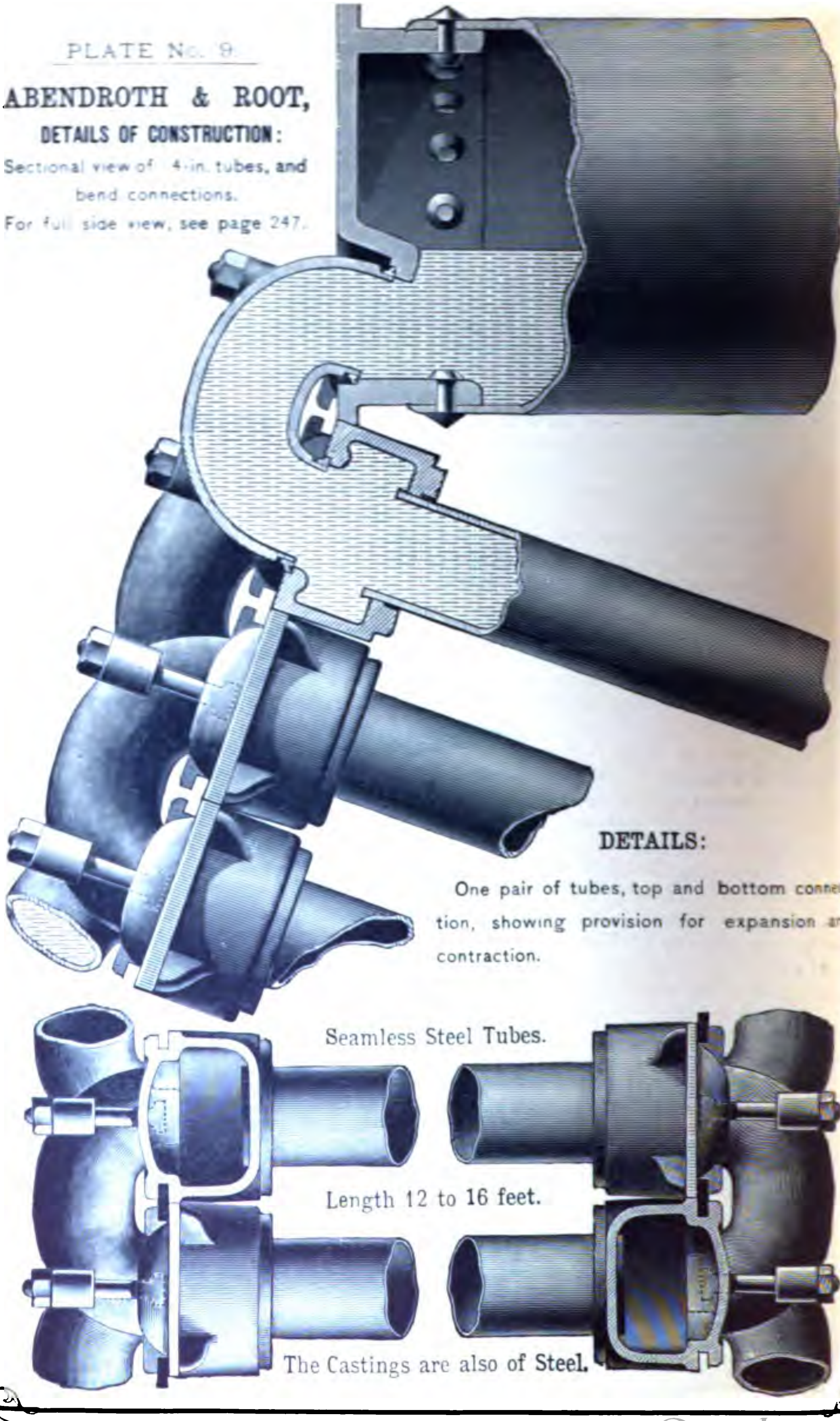
PLATE No. 9.

ABENDROTH & ROOT,

DETAILS OF CONSTRUCTION:

Sectional view of 4-in. tubes, and bend connections.

For full side view, see page 247.



DETAILS:

One pair of tubes, top and bottom connection, showing provision for expansion and contraction.

THE WATER TUBE SAFETY BOILERS.*

PLATE No. 10.

For description of grate, see page 114.

* Abendroth & Root, Manufacturers, No. 28 Cliff St., New York City.

ORIGINAL MILLS SAFETY STEAM GENERATOR, NO. 3.

EMPLOYED AT FRANKLIN, N. Y., AND TESTED BY HEWINS & TOWER, 1872.

WATERTOWN, July 20, 1872.

GEO. W. WALKER & Co., Boston, Mass.

This is to certify that we tested at our foundry, March 15, 1872, two sections of Mills Generator, No. 3, by hydraulic pressure.

One section resisted a pressure of *six hundred and ninety pounds to the square inch.* The other, a No. 2, *six hundred and forty pounds.*

The sections were taken from a pile in the yard without selection.

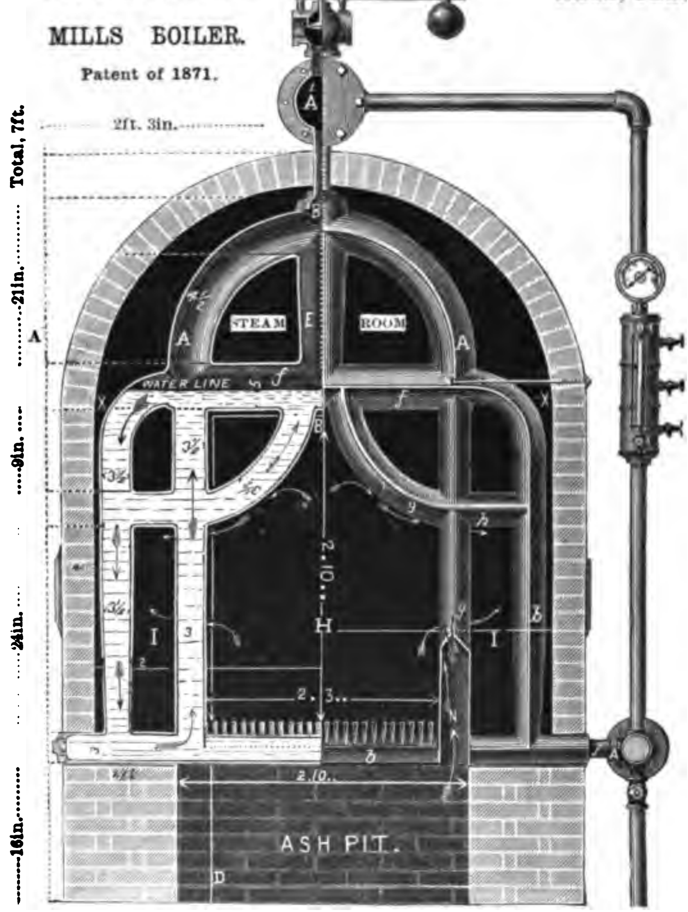
Respectfully yours,

MILES, PRATT & Co.

FIGURE No. 14.

MILLS BOILER.

Patent of 1871.



Elevation (one half in section) showing water line and circulation.

H, furnace; I, I, side flues and combustion chamber.

N, air pockets, formed on the sections (air above the fire).

A (1), steam dome; A (2), water and feed drum.

Heating surface *below* the water line, 16 feet; *above*, 4 feet = 20 square feet, or 2 H. P.

Grate surface, 1 square foot per section. Weight, about 400 lbs.

For horizontal view, when made up into generators, see bottom of plate No. 15 in the following section on cast-iron boilers; the above test of strength has been repeated many times. See pages 275. 276.

CAST IRON AS A MATERIAL FOR BOILER CONSTRUCTION.

We now come to a subject and a material over which there has been much discussion and much difference of opinion, and perhaps the writer will not be able to contribute anything new or valuable. Still, a personal experience of over twenty years in the use, construction, and operation of cast-iron boilers and radiators should not be without interest to the practical man or the student; and this, he trusts, will also exempt him from any charge of egotism or even of partiality in presenting for favorable notice a material and construction in which he has had a personal interest.

Certainly nothing less than a personal interest would induce the expenditure of the time and the money which the writer has contributed, and which has been found necessary to arrive at the facts underlying this construction and material.

In this, as in most of the other subjects treated, it will not be necessary to confine the review to a single or personal experience, since other and more able men have worked and written, with perhaps the disadvantage of not submitting extended experiments and contemporaneous proof of their conclusions.

The use and employment of cast iron for *boilers* and *radiators* has undergone a marked change in the last few years, even among engineers and those especially interested in wrought iron and its various applications to the same uses. For a long time after the first cast-iron boiler appeared, it was difficult to get even a fair hearing or any important consideration of the facts, owing to the limited knowledge and the prejudice existing among engineers and those who dealt in and used wrought-iron plates and tubes.

That the tensile strength of cast-iron plates of the same thickness is less than that of wrought iron, is acknowledged; but there any useful comparison ends, as no inventor has ever attempted to use cast *flat plates* for boiler surfaces, but, on the contrary, employs it in cylinders of small sectional area, in which form the available strength is far in excess of any possible requirement.

From a mean of many experiments it may be said that the ordinary castings have a tensile strength of fifteen thousand pounds per square inch, or 6.69 tons, and that, when care has been exercised in the selection and mixture of pig iron, castings may be made that show a strength of twelve to fifteen tons.

The elastic limit of cast iron varies somewhat, but is not far from o[illegible] third of the breaking strain. This would give five thousan[illegible] the limit of safety in common castings.

Allowing a factor of safety of ten, a working pressure would then be allowed of five hundred pounds; and this would give for sections of three-eighth inch thickness a safe working pressure of *one hundred and eighty-eight* pounds per square inch.

By the adoption of this principle, cast iron, although it does not possess as high a degree of tensile strength as wrought iron, is relieved of any objection that might be urged on the score of sufficient strength, and this, too, without such increase of the thickness of the metal as to interfere with the free transmission of the heat.

Not to follow this question of the strength unduly, as nearly every engineer understands it, we will, however, call the attention of the timid ones to a few simple facts connected with what they sometimes regard as a weak material.

After the steam of the highest pressure has been made in the boiler, where is it next sent for duty? Why, to the *cast-iron cylinders* of the engine, to be sure; and, after it has been multiplied many times by the piston, the power is transmitted through a cross head and crank to the fly-wheel, and through other *cast-iron wheels and pulleys* to the various machines. In short, more cast iron is employed in the motor and moving part of machines under steam than either wrought iron or steel.

Then look at the locomotive, and the wheels that carry the whole train; nine tenths of these are cast iron or cast steel. And for guns — well, our main reliance for these weapons carrying the greatest strain is cast metal, sometimes re-enforced by bands or hoops of steel; and, lastly, it is safe to affirm that more cast metal is employed for carrying strain and stress than of either wrought iron or steel.

While cast iron was early employed as a material for steam boilers intended to carry high pressure, it fell into disrepute among engineers, from which it has only partially recovered, and now only to the extent of toleration for low pressure apparatus, and where employed in steam heating, and warming by water circulation.

This opposition arose mainly from fear of what *might* happen rather than from what did happen, as there have been but very few accidents, and less fatalities arising from rupture or breakage even under high pressure, undue and unnatural strains, than from any other class of boilers or materials employed; and it is safe to say, that for every dollar expended in the construction and perfection of cast-metal boilers or steam generators, a thousand has been spent in improving and experimenting with wrought iron and steel shell structures.

NOTE. — "Cast iron is not liable to be strained by inequality of temperature. It is liable to break or crack from such cause, and will give out at once if badly proportioned or improperly used; *and in this very quality lies its safety* — that of giving out at once when badly treated. Not so with wrought iron, its very tenacity begetting a false security, which may lead to disaster at any moment."

OFFICE OF SWEET'S MFG. CO.,

SYRACUSE, N. Y., June 5, 1874.

E. H. COOK & CO., ELMIRA, N. Y.

Gentlemen,— On March 1, 1873, we fired a heating furnace with one of J. H. Mills Boilers of eighteen sections over it. After various trials we found too much heat escaping up the chimney, and we ordered ten more sections April 15. Our regular steam pressure is eighty pounds.

We use our city water, which is very hard, producing the hardest scale, and one that does not yield to any boiler compound yet produced. The water was heated in a Frazier Heater, and all our boilers are fed from the same pump.

We used this boiler *one year and forty-five days*, when we took the third from the end section (at the end the flame entered) and broke it in pieces, so we could see all parts of it.

We found *comparatively no scale.* In the lower part of the boiler the carbonate scale was soft and easily blown off; the sulphide scale near the water line was less than *one sixteenth of an inch thick, and there was very little of it.*

I have a Mills Boiler in my house, and another, recently completed, in our new Steel Mill at *Giddes.*

The Mills Boiler has the best circulation, is the best steam producer, and the safest boiler I have ever used, or had brought to my notice, and with *proper blowing off will keep the freest from mud and scale.*

I consider it a perfect boiler in every respect.

[Signed]

Yours truly
W. A. Sweet

BOSTON, Oct. 1, 1877.

MR. JOHN H. MILLS :

Dear Sir,— With regard to the sectional boiler which we bought of you last May, we have to report that it gives us satisfaction. The order specified that the boiler should carry *one hundred and fifty pounds;* we have had that pressure on many times, and as high as *one hundred and sixty-five pounds without showing any leakage or other derangement.* [Signed]

Yours truly,
Wm A Park
Supt The Hancock Inspira[illegible] Co

CAST VERSUS WROUGHT IRON.*

"Some years ago a prominent iron manufacturer received a letter from the Franklin Scientific Institute of Philadelphia, requesting such information as might be derived from his experience touching the relative capacities of cast and wrought iron for the transmission of heat. Being the maker of a steam-heating apparatus, among other things, he was naturally interested in the subject, and set about making the investigation, which this inquiry suggested, in good earnest.

"He commenced a series of carefully conducted experiments with similar water vessels of equal capacity and thickness, made of the two different materials, and exposed for a certain length of time to the same degree of heat. The results, ascertained by thermometrical measurement, were carefully noted, and sent to the Franklin Institute. In every case they showed a large difference (more than 10 per cent) in favor of cast iron over wrought as a conductor of heat; the conclusion being, of course, that all apparatus designed for heating and cooking purposes should be constructed of the former material, with a view to securing the quickest and best results, with the most economical consumption of fuel.

"The correspondence relating to these experiments, we believe, has never been published; and the facts developed by it are mostly the property of abstract scientists, rather than of practical manufacturers and the great consuming public, who are mostly affected by it. The theory advanced by the gentlemen who made these experiments is, that wrought or malleable iron, which is a relatively pure metal, has a laminated structure, and that its flattened particles, lying side by side, after being rolled and hammered, present a strong resistance to the action of heat, and that, hence, articles made of it are relatively poor conductors, and slow to absorb and radiate caloric, if we may use an obsolete but very expressive and convenient scientific term.

"On the other hand, he argues that cast iron, which is not a pure metal, but, like plumbago and steel, a compound of iron and carbon (carburet of iron), has no such fibrous and impervious structure; but, being a brittle, granular, porous, and penetrable substance, readily absorbs heat, and as readily gives it out again to surrounding objects by radiation and conduction. The rougher the surface of the iron, the greater is its radiating power, and hence highly polished parlor stoves and steam heaters are less effective than those which present a natural surface, or are kept tidy with a coating of black lead."

* *The Iron Review*, March, 1886.

"The heat-transmitting power of the plate decreases with the thickness and the resistance, and conversely increases with the facility offered by its heat-absorbing, conducting, and emitting qualities; also the resistance is not directly proportional to the thickness or the conducting power of the plate. In consequence of the great superiority of the internal compared with the external conduction of copper, brass, iron, and steel, some eminent authorities conclude that the small difference in their conducting powers and thickness has no appreciable influence on the amount of heat that they transmit.

"Peclet, who found that all metals conduct about alike when their surfaces are dull, quotes two experiments which seem to bear out this conclusion. One was with a boiler of cast iron and the other with a boiler of copper. Both were exposed to a fierce fire and plunged in the flame. Each produced about twenty pounds of steam per square foot of surface per hour.

"Carefully conducted experiments and the results of practice show that after the first few days' work, with ordinary impure feed water, there is no perceptible difference in the evaporative power *of copper, brass, and iron tubes, although their relative internal conduction powers are respectively* 74, 24, 12; *and that so far as the economical use of fuel is concerned, there is no gain in employing the dearer metals.*"

The adaptability of cast iron for constructions exposed to such constant and severe strains as steam generators has been the subject of much discussion in the past among mechanical engineers. But the question, we think, may now be considered as beyond the pale of discussion, for the reason that the crucial test of successful practice has long since definitely settled the points of dispute. So long ago, in fact, as the year 1867–68, so eminent a body as the Committee of Science and Arts of the Franklin Institute of Pennsylvania placed themselves unqualifiedly on record as approving the use of cast iron for this purpose, and crowned with their highest award the inventor of a form of sectional steam generator of this kind.

Aside from this, the fact that such steam generators have been for years in service with satisfactory results, would itself be a sufficient answer to any objections raised on that point.

As regards strength or the ability to withstand a bursting strain, it is hardly necessary to remind our practical readers that, in this respect, the factor of proportion enters quite as importantly into the consideration as the factor of material, and that there are two ways in which we may increase the strength of a hollow vessel; first, by increasing the thickness of its walls, and *second, by diminishing its diameter.*

From such information as the writer has, he concludes that the credit of producing the first practical cast-iron boiler belongs to George B. Brayton, at the time a resident of Providence, R. I. Under date of April 20, 1888, Mr. Brayton transmitted to the writer a circular on his boiler construction and their adaptation to power purposes. It reads:—

"The first cast sectional steam boiler that had its parts bolted together was made by myself at Pottery Hill, Westerly, R. I., in 1849. It was mounted on a small locomotive, and run several trips on the ice covering the Powquetich River." Signed "Geo. B. Brayton."

It appears, however, from the same circular that it was some ten or twelve years later, 1864, before a practical and safe steam generator was placed in one of the principal buildings on Weybosset Street, Providence, R. I. This created much interest and some trepidation among the city authorities, who appointed a committee of scientists to investigate the character of the new construction. ***Mr. Brayton stated to the committee that the generator could be heated red-hot from the absence of water, and then cooled down to its regular conditions of action, by pumping cold water, without danger.***

After some hesitation the committee decided to have the trial made, which succeeded to the satisfaction of all present.

The committee reported so highly in favor of the invention that its free use was secured within the city limits.

In 1864, five additional patents were granted Mr. Brayton, one embracing a coil of pipe within a furnace; said coil was connected to a water and steam chamber located outside of the furnace, which was called the supplementary vessel. Water was fed to the coil in quantity, or to rather more than its full evaporative capacity; and the steam, together with the surplus water, was delivered through the side of the vessel, while the steam to be used was taken from the top of said vessel. In 1865, the invention, with slight modifications, was exhibited to the Charitable Mechanics' Association of Boston, and the committee, who gave it a thorough test, *awarded a gold medal.*

In the year 1866, another patent was granted to Mr. Brayton for an improved steam generator. A year later, in 1867, the writer first saw the Brayton safety boilers; they were then in portable settings, and had an engine on the base plate, and altogether made a very creditable appearance, and attracted much attention from engineers and others.

It must have been some years later, before the patents and patterns were transferred to Mr. Burlingame, proprietor of the Exeter Mac[illegible] Works, who gave the boiler its present name.

MASSACHUSETTS CHARITABLE MECHANICS' ASSOCIATION

AWARDED A GOLD MEDAL.

AMERICAN INSTITUTE FAIR,

MEDAL AND DIPLOMA.

Extracts from Report of the Committee on Science and the Arts, constituted by the "Franklin Institute of the State of Pennsylvania," to whom was referred for examination "the Exeter Sectional Boiler," as to its safety from explosions.

*** "'The Exeter Sectional Boiler' comes very near to it, if it does not solve that difficult problem of uniting small compartments composing a boiler of considerable size, and at the same time provide for the free escape of steam without lifting the water. Many sectional boilers are so constructed in combining their parts as to cause the steam generated in the lower portion of the apparatus to force its way in zigzag courses through a whole neighborhood of narrow passages or through a number of long, comparatively small, and nearly horizontal tubes, into which it is quite impossible for the water to promptly follow, as it should do in order to maintain perfect circulation, and take up all the transmitted heat before effecting its escape.**

"In many cases these upper sections are alike subjected to the direct action of fire, and become, under a moderate supply of steam, highly heated, rendering them liable to fracture, without increase of pressure from sudden changes in the height of the water.

"The water in the 'Exeter' section exists in vertical masses about three and one-fourth inches square and twenty-eight inches high, a form favorable to the ready liberation of the steam to and from the surface of the water, and securing at the same time prompt circulation and supply of water to the heated surfaces of the boiler.

"We find, on careful and extended inquiry, that the 'Exeter Boiler,' thus far in its existence and service, has an excellent record, sufficient to justify us in making the assertion that it is equally *as safe as any sectional boiler in the market* known to us.

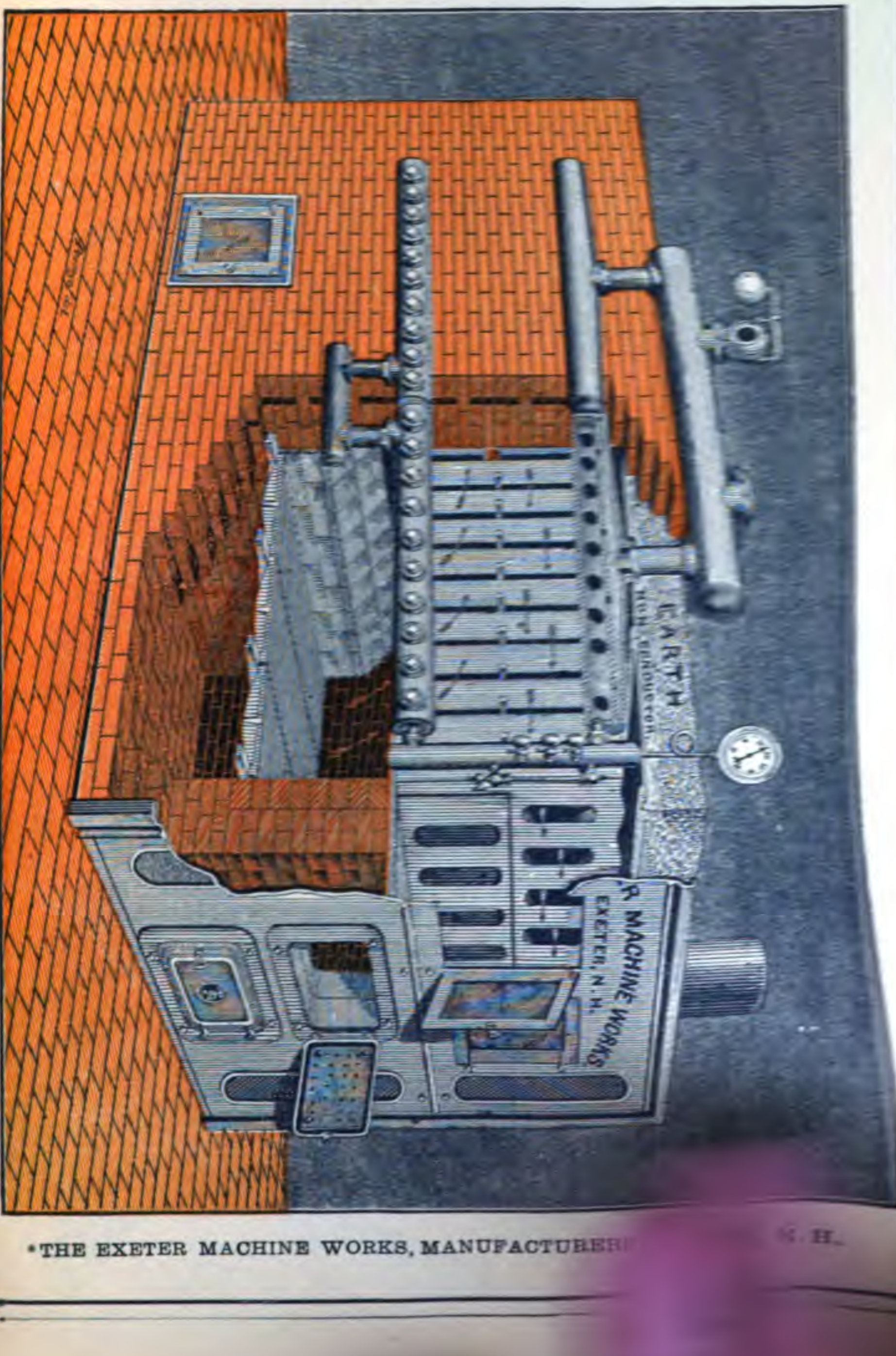
"We have not found any evidence, whether derived from the severest experimental tests to which a boiler can be subjected, or from long-continued daily use under the ordinary working conditions in the factory, which would prove it to be dangerous as a generator of steam."

*** Exeter Machine Works, Exeter, N. H.**

PLATE No. 11.

THE "EXETER" SECTIONAL BOILER.*

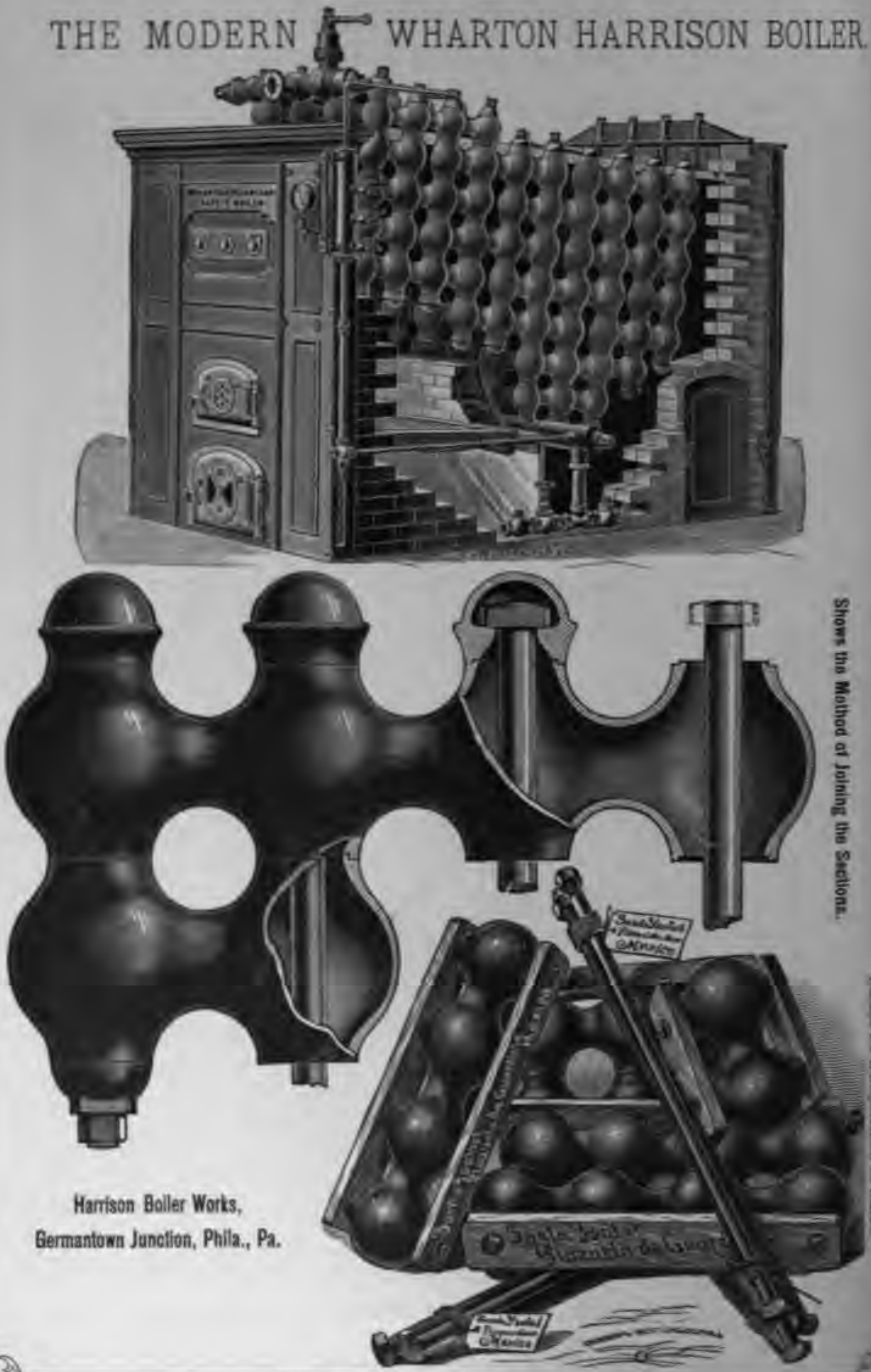
Formerly the "BRATTON" boiler.



*THE EXETER MACHINE WORKS, MANUFACTURERS, ... N. H.

PLATE No. 13.

THE MODERN WHARTON HARRISON BOILER.



Shows the Method of Joining the Sections.

Harrison Boiler Works,
Germantown Junction, Phila., Pa.

THE HARRISON CAST-IRON SECTIONAL BOILER.

Mr. Joseph Harrison, the inventor, was an eminent engineer of large practical experience and ample fortune, and, prior to his adopting cast metal as a material for a high-pressure steam generator, he made many and costly experiments with various forms of wrought and tubular construction, and he abandoned them all as failures to fulfill the ideal conditions laid down by himself and other prominent engineers.

It was first made in England, and exhibited at the International Exhibition in London in 1862. (Awarded first-class medal.) After importing several hundred tons of the boiler castings to this country, Mr. Harrison erected extensive works in Philadelphia, where thousands of horse-power were made annually, the works only shutting down for a time after his death, to be opened again by the present manufacturers.

The cut gives an excellent idea of the construction and general setting, the smaller cuts showing the general mechanical construction and method of packing for transportation.

To the axioms laid down by Mr. Harrison for a boiler construction, and the energetic and capable work done in the introduction of the Harrison boiler by his assistant, Mr. Coleman, may be traced the inspiration of succeeding inventors who have designed cast sectional boilers; and, indeed, there has little new ground been developed by those who have adopted the wrought or steel tubular construction (unless it be the supplementary steam and water drums). The angle at which Harrison set his heating surface, the large and efficient combustion chamber, are to be seen in all the modern sectional boilers, as the Babcock & Wilcox, the Abendroth & Root, and many others.

This elevation of the front end of all tubular constructions is clearly to aid the circulation of the water and facilitate the separation of the steam, and also to secure more room in the fire chamber than is possible with horizontal boilers, or boilers having a shell around tubes.

Whoever else has worked, and experimented, and produced a sectional and safety steam generator, certainly no man, from first to last, was so well fitted by birth, education, and surroundings to reach satisfactory results in a most difficult line of purely experimental engineering. That Mr. Harrison did reach it, is evinced by the mention his experiments and machines elicited both at home and abroad. That he also reaped a full and prompt reward is perhaps more surprising, but is also gratifying to all who have or would emulate his worthy example.

As the axioms adopted by the inventor are as valuable and desirable to-day as when Mr. Harrison laid them down for his guidance, we reproduce them with the advantages claimed for such a construction, and the results of evaporative tests. See table No. 7, page 265.

HARRISON'S AXIOMS FOR BOILER CONSTRUCTION.*

"1st. That a steam boiler, of whatever form or material, must, as a paramount condition, be absolutely safe from destructive explosion, even when carelessly used.

"2d. That it must be constructed upon a system, or series, of uniform parts, simple in form, few in number, easily put together or taken apart, and not of costly material.

"3d. That its strength should be in no ways dependent upon any system of stays or braces whereby the inefficiency or rupture of one of these braces or stays could cause greatly increased strain upon the others, thus endangering the whole structure.

"4th. That its parts should not be of great weight or size, thus affording greater portability and greater facility for getting it in or out of place.

"5th. That it must have a principle of renewal, allowing the easy displacement and replacement or interchange of any one or more of its parts, without disturbing or impairing the material or workmanship of the remaining portions of the structure.

"6th. That a boiler, whether of large or small dimensions, should have uniformly such elements of strength as would render it always capable of safely sustaining many times a greater pressure than need ever be demanded of it in practice; and that its safety should not be impaired by corrosion, or the many other harmful influences which so soon and so seriously affect the strength of ordinary boilers.

"7th. That the parts should be so made and so put together, that in case of rupture of any portion of the boiler no general break-up of the structure could occur, the release of the pressure by such rupture merely causing a discharge of the contents, without explosion or serious disturbance of any kind.

"8th. That it should be so constructed as to facilitate the certain removal of deposit from its interior or exterior surface."

While other inventors have perhaps labored as faithfully to improve an important machine or industry, perhaps none of them ever received so distinguished an acknowledgment from *scientific institutes*, from the *Secretary of the Treasury*, and lastly the *Rumford medal.*

While the origin of these medals is well known, there are many engineers and young men who could hardly tell who Count Rumford was, and his especial claim for remembrance. The following items of history are given a place here without apology, and are recommended to the perusal of those persons who find nothing of merit in a cast metal boiler construction.

* Harrison boiler circular.

AWARD OF THE RUMFORD MEDALS, 1871.

COUNT RUMFORD AND HIS USEFUL WORKS.

"An associated press telegram dated Boston, Jan. 9, 1871, announces that the 'American Academy of Arts and Sciences met that evening, for the purpose of presenting the Rumford medals to Joseph Harrison, Jr., of Philadelphia, for his invention of safety boilers.' The award of the medals was made at the last meeting of the Academy (1871); and the correspondence on the subject, together with a brief account of the origin of the fund, and of the previous awards of the medals, is here presented.

"Among the former recipients of the 'Rumford Medals' in America and in Europe, will be found the names of Dr. Robert Hare, of Philadelphia; John B. Erricson and George H. Corliss, of our own country; and Sir Humphrey Davy, Michael Faraday, Sir David Brewster, F. J. D. Farago, Henry Fox Talbot, Dr. Arnott, and John Tyndall, abroad. In the United States the medals are provided for by a fund, placed by Count Rumford in the hands of the American Academy of Arts and Sciences, Boston, and in Europe by a similar fund placed in charge of the Royal Society, London.

"The recent award in the United States recalls to mind the highly useful works of a remarkable man whose memory is chiefly identified with European countries, — England, Bavaria, and France, — although he was an American by birth, and grew to manhood on this side of the Atlantic. The man who subsequently became so famous as 'Count Rumford' was a native of the little village of Woburn, near Boston, born in March, 1753. His name was Benjamin Thompson. Left an orphan in his infancy by the death of his father, he got the village school education of those early days; was apprenticed 1766 to an importer of British goods in Salem, Mass., reading, studying, working at mechanical contrivances, dabbling in philosophy, and going to school and to lectures at intervals; married in his twentieth year, and appointed Major to the colonial forces; fell under suspicion as to his loyalty at the outbreak of the Revolution; was threatened with mob violence; fled from his home (Concord), got within the British lines at Boston, and went to England in 1776. After that his career was very eventful.

"He was appointed Under Secretary of State for the Colonies, possessing great influence with Lord George Germaine; came back to America (1781) as Colonel of a regiment of cavalry in the British service; returned to England (1785); went soon after (still being a British officer) to France, where he attracted the notice of the Elector

of Bavaria by his fine appearance on horseback; was invited to Munich, having first been knighted in England; and in Munich he arose in a few years to be the confidential adviser of the sovereign, chief officer of State, Commander in Chief of the army, and Minister to England; having in the mean time established a military academy, military workshops to promote industry among the soldiers, improved roads, established a noble park at Munich, abolished a deplorable state of mendicancy in the city by providing industrial homes for the poor, and made many valuable improvements and discoveries in the application of science to the mechanic arts and domestic affairs.

"For all this he was made 'Count Rumford.'

"He returned to England in 1795, founded the 'Royal Institution,' which has given to the world the invaluable discoveries of Humphrey Davy, Michael Faraday, and John Tyndall; endowed the Royal Society and the American Academy with the funds for the Rumford Medals; went to Paris in 1803, continued his philosophical investigations there until 1814, when he died, leaving the residue of his estate to Harvard University, Cambridge, Mass.

"The career, of which the foregoing is the barest skeleton of a sketch, was as wondrous as a romance.

"But the most remarkable characteristic of the man, after the magnetic attractions of his manner, was the tenacity with which he held, and the energy with which he urged, his idea of bringing science to bear on the practical affairs and employments of common life. Whenever he was engaged in his laboratory, experimenting on the properties of heat and the developments of chemistry, he was always on the lookout for some methods of utilizing his discoveries in the improvement of chimneys, fireplaces, grates, stoves, ovens, lamps, furnaces to steam engines, cooking utensils, etc. He taught England how to avoid waste of fuel, how to construct chimneys that would not smoke, how to build fireplaces, and how to erect kitchens for great hospitals; and he taught Bavaria how to make even the beggars self-supporting, and how to prevent the soldiers from becoming drones and demoralizers of society, by giving them incentives to be industrious in camp.

"Nothing was beneath his craving to improve everything, and he employed himself as readily in improving a kitchen roaster or a sawhorse for a wood sawyer, as in his inquiries into the abstract principles of heat, light, and chemistry. His uppermost thought was to have science directed 'to the improvement of arts and manufactures,' 'the encouragement of industry,' the promotion of 'the comforts and conveniences of life,' especially 'among the poorer and more numerous classes of society.'"

REPLY OF MR. HARRISON.

TO THE PRESIDENT AND MEMBERS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES.

Mr. President and Gentlemen: In receiving the Rumford medals, which have been awarded me in such a flattering manner by the American Academy of Arts and Sciences, I fear I cannot express in suitable terms my appreciation of this distinguished honor. I can therefore only say that I do esteem this compliment very highly indeed, and I shall ever cherish these tokens with the greatest pride. To my mind there is nothing within the limits of science, at the present time, that is of more importance than the application of heat to the safe generation of steam; and to have won an acknowledged distinction in such a field, and to have been deemed worthy of the reward that your honorable society has bestowed upon me, fully repays me for many years of anxious and often of discouraging effort. In what I have done, I claim but little merit beyond having called attention for the last twelve years to the great importance of the question, and in having, in some degree, demonstrated the fact that a steam generator can be made secure from disastrous explosion. I think that this idea has now taken such a firm hold on the public mind, both in this country and in Europe, that it may be fairly inferred that, in the future, the use of the steam boiler under pressure, no matter what form the apparatus may eventually assume, will not be attended by the disastrous results that are recorded in the past. In expressing my regret in being unable to attend your meeting of January the 9th, so as to receive the medals in person, I most sincerely thank you, Mr. President, and the members of the American Society of Arts and Sciences, for this very high mark of your approbation.

JOSEPH HARRISON, JR.

The following from *Appleton's Cyclopedia of Biography* seems a fitting conclusion to those items of history: —

"Joseph Harrison, born in Philadelphia, Pa., Sept. 20, 1810, died the 27th of March, 1874. He had received but a partial common school education, when his strong inclination for mechanical pursuits led his father to indenture him to learn steam engineering. He began to build steam locomotives in 1834, and in 1840 designed for the Reading Railroad an eleven-ton engine. Two Russian engineers, Col. Melnekoff and Col. Kraft, who were in this country to investigate its railway system, saw his engine and took traces of it, and introduced it into general use in Russia, where its value led to an official inquiry as to its builder. The result was that Mr. Harrison was invited to Russia; and there in 1843, he, with Andrew M. Eastwick, of Philadelphia, and Thomas Winans, of Baltimore, concluded a contract with the government to build the locomotives and rolling stock for the St. Petersburg & Moscow Railroad for $3,000,000. The Emperor Nicholas made the partners costly presents, and also gave Mr. Harrison the ribbon of the Order of St. Ann, to which he attached a massive gold medal at the time of the completion of the bridge across the Neva. After executing other important contracts for the Russian government, Mr. Harrison returned to Philadelphia in 1852, built a fine mansion, and collected in it many paintings and other works of art. Later he designed and patented the "Harrison Safety Boiler," and was awarded the gold and silver Rumford medals by the American Academy of Arts and Sciences.

He wrote "The Iron Worker and King Solomon," and published a folio containing this poem and some fugitive pieces, his autobiography, and many incidents of his life in Russia. (Philadelphia, 1869.) He also wrote a paper on the part taken by Philadelphians in the invention of the locomotive, an account of the Neva bridge in Russia, and a paper on steam boilers.

He was a member of the American Philosophical Society, and of other societies.

BOILER EXPERIMENTS.—THE EVAPORATIVE POWER OF COAL.*

By this is meant the number of pounds of water, which, under certain conditions, are capable of being evaporated per pound of coal. It is essential to the obtaining of exact results, that the temperature of the feed water and the temperature of evaporation should both be ascertained, and the total heat per pound of water computed. That total heat being divided by 966, the latent heat of evaporation of a pound of water at 212°, gives a multiplier by which the weight of water actually evaporated by each pound of fuel is to be multiplied, to reduce it to the equivalent evaporation from and at 212°; that is, the weight of water which would have been evaporated by each pound of fuel, had the water been both supplied and evaporated at the boiling point corresponding to the mean atmospheric pressure. The weight of water so calculated is called the evaporative power of the fuel.

The object of reducing evaporative results in practice to equivalent evaporation from and at 212°, is to afford an intelligible basis of comparison between different kinds of fuel.

To make such a comparison, it is necessary to know the pressure and temperature of the steam; the temperature of the feed water; the number of pounds of coal burned on the grate (deducting the ashes, if the net combustible is desired); and the number of pounds of water evaporated in a given time. From these last two items the ratio of coal or net combustible to evaporation may be easily determined by dividing the number of pounds of water evaporated by the number of pounds of coal burned in an hour, a day, or any other given time.

Example.— A boiler evaporating eight pounds of water per pound of coal (net), the temperature of the feed water being 85° Fahr., and the pressure of the steam in the boiler seventy-five pounds per square inch above the atmosphere; what is the equivalent evaporation per pound of coal at atmospheric pressure from and at 212°?

The total heat required to generate one pound of steam from water at 32° Fahr., under a constant pressure of seventy-five pounds per square inch, is (Table No. 14) 1,179 units.

The water entering the boiler at a temperature of 85° instead of 32°, there is a gain of 85°—32°=53°.

Then, 1,179—53=1,126 units of heat.

The units of heat required to convert one pound of water at 212° into steam, at atmospheric pressure, = 966 (Table 14; atmospheric pressure corresponds to zero *gauge* pressure).

1,126 divided by 966=1.17, the multiplier.

8 x 1.17=9.36 pounds of water, the equivalent evaporation per pound of coal net, at atmospheric pressure, from and at a temperature of 212°.

* *Combustion of Coal*, by Wm. Barr, 1879.

TABLE No. 7.

EVAPORATIVE TESTS WITH DIFFERENT BOILERS AND FURNACES

CYLINDER, FLUE, TUBULAR, SECTIONAL SAFETY AND CAST IRON BOILERS.

No. for Reference.	BOILERS. DESCRIPTION.	AUTHORITIES.	A Time of Test.	B Boiler Surface Exposed to Heat.	C Grate Surface.	D Horse Power G x K ÷ 34.4.	E Steam Gauge Press.	F Temp. of Feed Water.	G Fuel. Coal per Hour.	H Fuel. Combustible per Hour.	I *Water Evaporated* per Lb. of Coal from Temp. of Feed.	J Equiv. E. from and at 212°. Pr. Ft. Heating Surface per Hr. G x K ÷ B.	K Per Lb. of Coal.	L Per Pound of Combustible K x G ÷ H.	
	WROUGHT IRON AND STEEL BOILERS.		HRS.	SQ. FT.	SQ. FT.		LBS.	DEGS.	LBS.	LBS.	LBS.	LBS.	LBS.	LBS.	
1	French or Elephant, Cylinder Externally Fired,	French Experiments at Mulhouse, 1874.	33	608	20.	58	68	82	222.6	192.5	7.68	3.28	8.97	10.37	10.81
2	Fairbairn, English, Flue Internally Fired......		33	1017	20.5	57	68	79	216	185.5	7.73	1.90	9.05	10.44	
3	Lancashire, English, Double Flue Internally Fired,		33	613	20.5	57	68	81	208.2	177.6	7.95	3.16	9.29	10.89	
4	Drop Flue or Marine Boiler, Buffalo, N. Y...........	J. H. Mills, 1886.	8	1200	36	92	35	44	341	299	7.78	2.64	9.30	10.61	
5	Six Flue Boiler (Butman Pat. Furnace), Dayton, O.,	I. V. Holmes, 1877.	12	....	....	78	48	106	286	270	8.31	....	9.44	10.00	
6	Return Tubular (Jarvis Pat. Furnace),	Edison Electric Light Co., 1883.	12	1626	37.4	229	77	178	809	690	9.11	4.88	9.74	11.42	
7	Bigelow, Return Tubular, New Haven, Conn.,	L. Candee Co., 1879.	11	1178	32	128	80	65	418.2	359.7	8.86	2.07	10.52	12.23	
8	Smith, Cylindrical, Tubular with additional surf.	1876. U. S. Centennial Exhibition, Philadelphia, Pa.	8	1154	25	93	70	62	303.7	269.9	9.01	2.79	10.58	11.91	
9	Peirce, Cylinder Boiler Revolved on Trunnions		8	349	25	52	70	53	199.9	177.9	7.86	5.11	8.92	10.02	
10	Hoadley, Portable Engine, Locomotive Boiler ..		6	462	12.8	65	125	183	268.7	237	7.65	4.82	8.28	9.34	
11	Lowe,* Return Tubular (Fire through the Tubes)		8	754	22.5	47	70	66	153.1	135.8	8.89	2.15	10.57	11.92	
12	Rogers & Black, Vertical. (Tubes outside)....		8	400	21	46	70	67	181.7	163.8	7.47	3.93	8.66	9.61	
13	Galloway, Vertical Conical Tubes (Steel Shell)		8	853	36	103	70	56	346	307.5	8.61	4.18	10.39	11.58	
14	Andrews, Double Return, Marine Tubular		8	506	18.4	43	70	65	148.2	132.9	8.04	2.90	9.90	11.04	
15	Root,* Inclined Tubes, **Sectional Safety Boiler.**	Economy Tests from Official Reports of Gen. F. A. Walker, Chief of the Bureau of Awards.	8	1598	42	120	70	65	381.7	341.7	8.93	2.59	10.82	12.09	11.37
16	Firmenich, Vertical Tubes, " " "		8	1031	15.4	58	70	69	185.3	166.1	8.94	1.93	10.75	11.99	
17	Babcock & Wilcox, Incl. Tubes, " " "		8	1676	44.5	136	70	64	444.4	395.6	9.11	2.79	10.52	11.82	
18	Anderson, Horizontal Tubes, " " "		8	1115	36	98	70	54	350.9	318.4	7.98	3.03	9.64	10.62	
19	Kelley, Inclined Tubes, " " "		8	636	27.5	81	70	67	297.6	270.8	8.40	4.39	9.38	10.31	
	CAST IRON SECTIONAL BOILERS.														
20	Harrison Boiler,* Connected Hollow Globes...		8	901	23	82	70	71	284.4	260.2	8.56	3.16	10.00	10.93	11.28
21	Wiegand Sectional Boiler, Drop Tubes........		8	1339	42	148	70	71	518.9	469.6	8.22	3.80	9.80	10.83	
22	Exeter Boiler (Invented by Geo. Brayton, 1849–'64)		8	1563	30	72	70	69	280.6	248.6	7.83	1.60	8.90	10.04	
23	Mills, No. 5, Buffalo, N.Y..........................	Wm. Allen, 1883.	8	400	10	34	27	50	98	....	9.97	2.90	11.83	....	
24	" " 6, (Brightman Stoker) Springfield, Mass.....	J. H. Mills, 1887.	10	858	16	64	30	40	188	175	9.80	2.57	11.74	12.60	
25	" " 6, Soft Coal, Springfield, Mass............	" " " 1887.	5	858	20	49	30	40	176	162	8.03	1.97	9.62	10.45	
26	" " 6, Anthracite Coal, Buffalo, N. Y..........	" " " 1887.	8	858	26	67	35	44	238	199	8.06	2.67	9.64	11.53	
27	" " 3,* Boston, Mass..................	Col. E. H. Hewins, 1871.	20	283	10.1	20	3	44	63	48	9.23	2.41	10.86	11.20	
28	" " 3,* " "	" " " 1873.	9½	238	9.5	22	85	150	69.6	64.3	10.10	3.25	11.11	12.01	
29	" " 3, Ex. Chief Engineer, U. S. N.........	G. B. N. Tower, 1873.	10	283	10.1	18	30	43	60	46	8.85	2.25	10.58	10.85	
30	" " 5, Chief Engineer, G. R. & I. R. R.......	M. M. Stimson, 1881.	10	400	11	31	0	40	100	85.6	9.00	2.65	10.60	12.37	

(*See Cuts.) **Averages of the above:—Grate to Heating Surface, 1 : 32.8. Coal per Sq. Ft. of Grate per Hour, 10.8 Lbs.** 8.53 2.92 9.98 11.07

TABLE No. 7½.

EXPERIMENTS OF J. C. HOADLEY, AT LAWRENCE, MASS., TO DETERMINE THE VALUE OF FORCED DRAUGHT AND PRE-HEATING OF THE AIR.* DURATION OF EXPERIMENTS, 9 WEEKS.	PACIFIC BOILER. CHIMNEY DR'GHT. Anthracite.	PACIFIC BOILER. CHIMNEY DR'GHT. Bituminous.	WARM BLAST No. 1. Anthracite.	WARM BLAST No. 1. Bituminous.	WARM BLAST No. 2. Anthracite.
Coal consumed, net, per week, lbs.,	16,264	12,890	20,368	15,184	16,740
Water evaporated per week, lbs.,	147,039	121,590	180,542	145,076	157,483
Pounds of water per pound of coal,	9.04	9.43	8.86	9.55	9.41
Mean temperature of feed water,	71.90°	72.40°	38°	36°	49°
Mean temperature of external air, days,	73.30°	71.00°	34°	34.2°	49°
Steam-gauge pressure above atmosphere, pounds per square inch,	47.54	47.30	54.40	64.40	42.5
Mean barometric pressure, pounds per square inch,	14.47	14.61	14.64	14.66	14.70
Steam-pressure, absolute,	62.01	61.91	69.04	79.06	57.20
Pounds of water evaporated from and at 212° Fah., per pound of coal, days and nights,	10.51	10.58	10.81	11.54	11.12
Water evaporated from and at 212° Fah., by day, per pound of coal burned during days and nights,	9.31	9.22	10.00	10.72	10.77
Evaporative power of coal,	13.56	14.27	13.45	14.30	13.61
Efficiency, days and nights, per cent,	77.48	76.73	80.37	80.70	81.74
Efficiency, days, per cent,	79.96	76.53	87.05	84.21	87.76
Efficiency, water, days, per cent,	68.87	64.61	74.35	74.96	79.20
Losses, per cent, complement of efficiency; water, days only; coal, days and nights,	31.13	25.39	25.65	25.04	20.80
Losses, per cent, at chimney by radiation from brickwork, and by imperfect combustion — C O.,	17.75	17.03	15.00	14.24	12.83
Radiation,	2.64	3.39	4.00	4.00	4.00
C O.,	2.13	2.85	0.63	1.06	1.43
	22.52	23.27	19.63	19.30	18.26
Temperature of Furnace Gases before passing through abstractors,	368.3°	376.9°	396.9°	397.4°	377°
Temperature of air supplied to furnace: Fah.,	78.3°	71°	337.7°	349.5°	334°
Temperature of escaping gases,	368.3°	376.9°	189°	196°	164°
Gases cooled by Abstractors,	0	0	207.9°	201.4°	213°
Air warmed by Abstractors,	0	0	303.7°	315.5°	285°
Temperature of steam, days,	297.5°	297.3°	361.1°	322.6°	291.2°
Difference of t, boiler and gases,	70.8°	79.6°	127.1°	126.6°	127.2°
Difference of t, boiler and air supply,	above 219.2° below	above 226.3° below	below 21.6° above	below 26.3° above	below 42.8° above
Pounds of flue-gases per pound of coal: days,	22.39	25.23	23.49	28.37	24.17
Pounds of water equivalent in heat capacity to flue-gases per pound of coal; sp. heat of gases = 0.238,	5.33	6.00	5.59	6.75	5.75
British thermal units carried off in gases per pound of coal, days,	1,576	1,835	866	1,090	661
Efficiency *corrected* for difference in temperature of external air, and difference in time of banking fires,	68.87	64.61	78.18	77.50	81.43
Difference of efficiency: Pounds gained by warm blast, over Pacific Boiler, cold blast,	. . . .	. . . .	9.31	12.98	12.56
Ratio of gain to the larger quantity ($\frac{9}{78}$:$\frac{31}{18}$ = 11.9 per cent, etc.),	. . . .	. . . .	11.9	16.7	15.4
Ratio of gain to the smaller quantity ($\frac{9}{68}$:$\frac{31}{87}$ = 13.5 per cent, etc.),	. . . .	. . . .	13.5	20.1	18.2

* *Sanitary Engineer*, 1885.

DATA AND CONDITIONS OF LAWRENCE, MASS., BOILER EXPERIMENTS, 1885.*

Report of a series of trials made with a warm-blast apparatus for transferring a part of the heat of escaping flue gases to the furnace. By J. C. Hoadley, Boston, Mass.

Article in the *Sanitary Engineer*, July, 1885.

Experiments reported in this paper were begun in 1881 at the chemical shops of the Pacific Mills, Lawrence, Mass., by Mr. Fred H. Prentiss, under the direction of Mr. J. C. Hoadley. *The boiler tests lasted nine full weeks.* The warm-blast apparatus seems to afford a means of securing a net saving of 10 to 18 per cent over the best attainable practice with open chimney draught, and with air supplied to the furnace at usual temperatures of the outside air.

The objects of the experiments are stated to have been:—

1st. To ascertain how large a proportion of the heat generated in a boiler furnace escapes through the chimney.

2d. To ascertain the proportion of the escaping heat that could practically be arrested to be returned to the furnace in a warm blast by an admissible apparatus.

3d. To determine the form and dimensions of such an apparatus.

4th. To ascertain the loss of running a suction blower to replace the loss of draught in the chimney.

5th. To obtain by observation the data for striking a balance of advantages and disadvantages arising from the use of such an apparatus.

6th. To obtain as much information as such experiments could be made to yield on all questions relating to the economical combustion of coals and the generation of steam.

In carrying this out, a boiler similar in form, dimensions, and setting to all the fifty boilers at the Pacific Mills was tested, to ascertain to how near theoretically perfect conditions that boiler could be brought in actual practice week by week.

To find out just what proportion of the inevitable loss of heat was suffered at the chimney, and what degree of efficiency was attainable.

The observations covered coal, refuse, water, air, products of combustion, steam furnace fire, infiltration through brickwork, and temperature at all points.

The evaporation tests were each for one week, each day's work being plotted. The fuel was analyzed. The two boilers were externally fired, return tubular boilers, sixty inches in diameter, twenty feet long, of three-eighth inch plate, and with sixty tubes of three and one-half inches in diameter.

The abstractors for taking out the heat from the escaping gases consisted of two sets of wrought-iron, lap-welded tubes, two inches in diameter, one hundred and twenty in a set. Each pipe was incased in a three-inch tube of wrought iron. The air passed in the annular space outside the opening, inside the outer casing, the smoke passing through the inner two-inch tubes. Air was admitted from without the boiler-house, and was drawn through the abstractor into the ash pit and through the fire by the blower. The casing tubes were so adjusted to the air inlet as to secure equal currents through each tier. In a modified form of abstractor, used during the tests, the air was drawn across the hot pipes several times by means of diaphragm deflectors, and thus made to take up as much heat as possible, while the construction was less costly.

The results with anthracite in the Pacific boiler are the means for five weekly trials; all the others are for single weekly trials.

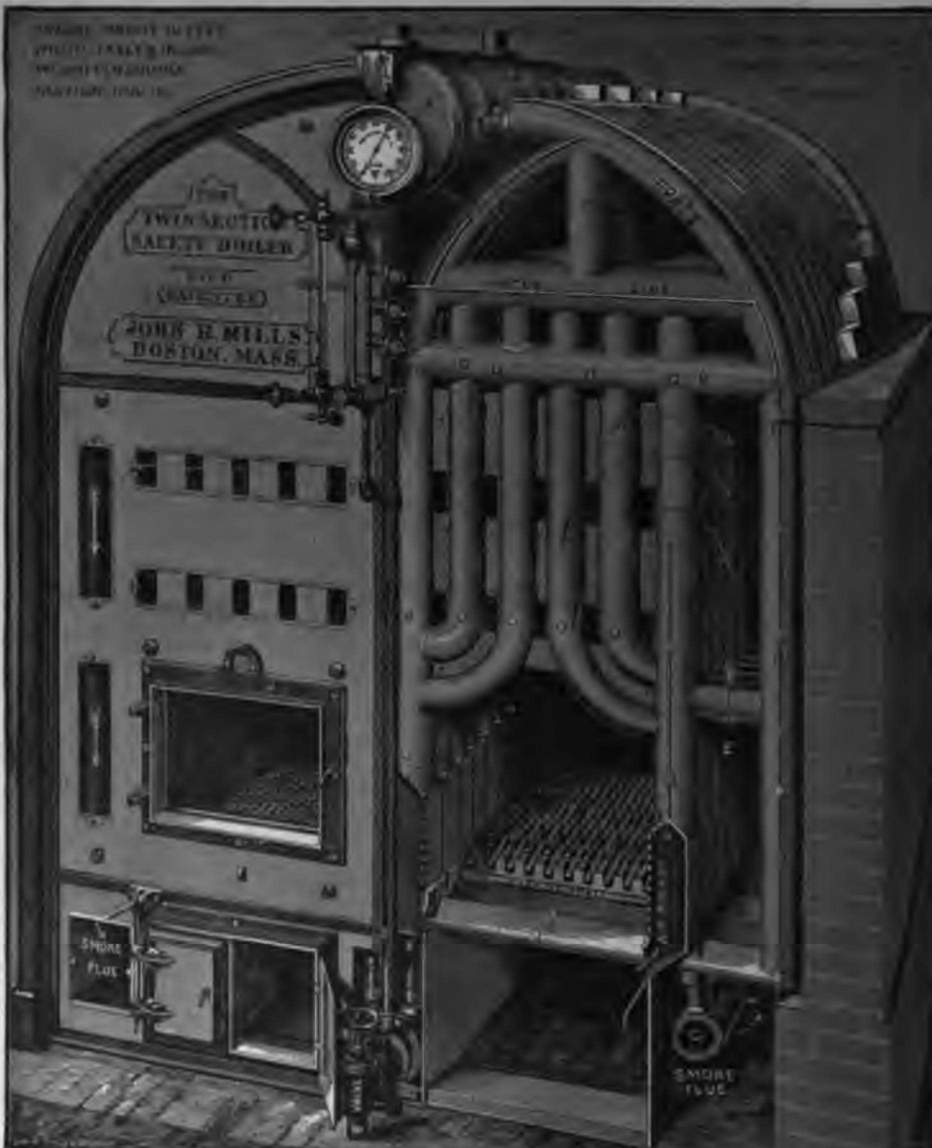
The power consumed in driving the blower is *about* 1 *per cent of the whole power* produced by the boiler in combination with a good steam engine.

It therefore appears that *the net saving effected by the warm and forced blast was from* 10.7 *to* 15.5 *per cent of the fuel used with the cold blast, which* [illegible] *the same thing as to say that discontinuing the warm blast would cause an increa*[illegible]*ption of fuel equal to about* 12.3 *to* 18.9 *per cent of the quantity used in the hot* [illegible]*dly stated, the gain is* 10 *to* 18 *per cent.*

* *The Sanitary Engineer*, July, 1885. See accompanying [illegible]

PLATE No. 14.

MILLS STEAM AND WATER SAFETY BOILER, No. 6.



Regular steam and water circulating boiler of 50 to 100 horse-power. Three of these are in use at the Pierce Building, Boston, Mass., three at the county buildings, Springfield, Mass., and three at State Prison, Cranston, R. I. (See evaporative experiment, page 265.)

CHAPTER XVI

THE MILLS AND OTHER HEATING BOILERS.

HAVING devoted considerable space and time to subjects of general interest, and to the constructions of other inventors, it will hardly be expected that the author should display a modesty equal to the overlooking of his own constructions and their application to various heating and ventilating operations.

Certainly, in view of the late rush of veterans and amateurs into the field of heating and heating appliances, it seems quite possible that the early inventors and pioneers in these fields should find it necessary to say something for themselves, the methods and machines which have helped to create the present healthy demand for warming by steam and water apparatus.

Where a few years ago there were a dozen boilers and radiators of special construction, and adapted to their several uses by many applications, there are to-day a hundred, each clamoring for place and recognition. That many possess merit, should go without saying; that some are deficient in essentials, is no less true.

The author's patents on cast-metal sectional boilers are dated 1867, 1869, 1871, 1872, 1874, and 1888. The portable water boiler shown on page 290 is the last of its race.

The first practicable boiler, however, was that of 1872; and its manufacture was begun by Geo. W. Walker & Co., at Watertown, Mass., at the foundry of Miles Pratt & Co. See letters of that date.

There was a further improvement in the patent of 1873, by which the products of combustion were turned from a horizontal to a *vertical direction*, the smoke finding exit in side passages *downwards*, and into the smoke flues *below the grate level;* it was this change in the direction and action of the heat upon the tubes that raised this boiler to a place worthy the attention of engineers, and that has since enabled it to retain its hold against all comers, and gives it to-day a record of [illegible] years' continuous manufacture and use, both for high and low pr[illegible] work, and for supplying steam power. (See pages 251, 252.)

In 1874 the patterns were removed to Westfield, to the foundry of the H. B. Smith Company, who had then commenced the manufacture of cored castings, the superior quality of which has built up from small beginnings a business of half a million a year, and carried their name into every state requiring heating apparatus.

The celebrated Gold's boiler and pin radiator, before referred to, is also the product of their foundry, as well as several other cast-iron specialties, including the Whittier, Reed, and Union radiators,—about which more will be said under the proper and special heading.

In the writer's construction of sectional boilers, the solution of several important questions has been met in a way radically different from former or later constructions, as may be seen by examination of the cuts and the preceding chapter.

The leading ideas embodied in the Mills boiler are:—

1st. The construction of an entire steam generator at one operation of molding and casting; the plan, grouping, and area of tubes, steam and water spaces being such as to secure the needed strength, ample passage ways for steam and water circulation, so that, if set up and fired as one unit, or united in a hundred units, the *functions of work and duty would always remain the same;* and that any injury to a section or unit affected only the individual unit, and to the extent of the surface involved, so that, if a section were the fiftieth part of a fifty horse-power boiler, it was weakened to that extent only. This valuable feature was secured, and has been many times tested practically (since engineers and firemen are not yet satisfied that two trains cannot pass on the same track at the same time, or that boiler surfaces cannot safely be *under fire without water*).

2d. To secure a reasonable amount of economy of fuel consumption in boilers of small dimensions. In heating operations boilers of five, ten, fifteen, and twenty horse-power are employed, but nearly always with a corresponding loss, due to increased radiation and *decreased absorbing and grate surfaces.*

3d. To place the water absorbing tubes and surfaces in *vertical* position, and so arranged that the fire should act in substantially the same lines, rising to the crown or highest surfaces, and *descending to the lowest in finding exit to the chimney*, which, by this plan, is really extended below the boiler, and is seen in the two divided flues—*one on each side of the ash pit below the grate.* By this action of the fire in *vertical lines* and exit of the products of combustion from the *lowest* and *coolest* instead of the highest and hottest portions of the boiler, an economy is effected not to be reached by any other arrangement of heating surfaces.

That this is so, may be inferred from the fact that nearly all of the first-class stoves and furnaces are to-day what are called "*base burners;*" that is, they *return* the smoke and waste products of combustion to the base instead of allowing them to escape from the top and hottest point to the chimney.

In the case of stoves and furnaces there is not, however, the same economy to be derived as with boilers so arranged, as it is not alone additional heating surface that is thus secured, but additional heating surface of a *lower temperature*, thus insuring a greater abstraction of heat; as, *the greater the difference between the temperature of the gases and the surface in contact, the greater amount of heat surrendered in a given time.*

4th. As *time*, then, is a factor involved, and not to be lost sight of, the longer the gases are in contact with the heating and absorbing surfaces, the greater will be the work done with a given amount of fuel. Thus, if the vertical height of the boiler is six feet to the crown or water line and the fire return to and below the level of the grate, the distance the fire travels will be twelve feet, and double the time will be occupied in its exit from the furnace, and thus less heat will escape to the chimney.

5th. Relation of the surfaces to the heat acting on them.

It is a well-known fact to all practical engineers and firemen that one foot of heating and absorbing surface in or over the fire box or furnace is worth several in other and remoter positions, and this is also true of every foot of surface that the fire *shines on;* and this brings us to the consideration of *radiant* heat and its value in heating and condensing operations.

While every owner of furnaces and the man who fires them may know that the surface in his fire box is really worth so much more, he may not know exactly or scientifically why this is so; therefore, we will say a few words explanatory of this subject, which will be taken up again later, and treated more fully under the head of radiators.

6th. Radiant heat, as related to fire and hot surfaces, may be said to leave the particles of flame or incandescent surfaces *in straight lines*, seeking always a cooler surface than itself, and that the greater the *difference in the temperature*, the greater the amount of heat lost by the hot and gained by the cooler surfaces *in a given time.* The greater the amount of absorbing surface within the *direct* and *unobstructed* rays of heat, the greater the effect on the surface so situated.

Therefore, all partitions introduced to guide the fire in certain directions, as to and fro horizontally, while delaying the exit of the gases, *diminish the effect of the radiant heat, or the heat of direct contact.*

The radiation from solid incandescent fuel is greater than from flame, while transparent hot gases scarcely radiate any heat at all. The more intense the contact heat of the flame by thorough mixture with air, the less is the heat by radiation.

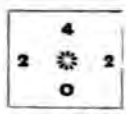
Conduction is the transfer of heat, either between the particles of the same body or between the parts of different bodies in contact, and it is distinguished respectively as internal and external conduction. The rate at which the former takes place in metal plates is very much greater than the latter, where the heat passes from the hot gases to the plates, and from these again to the water.

This is illustrated in the common horizontal tubular boiler, the heating surfaces of which are proportioned substantially, so that half of the shell represents one fifth of the total surface, and the surface of the tubes the other four fifths. The radiant heat from the fire reaches, say, but one half of the shell exposed, or the lower part of the shell *forward* of the bridge wall.

In a thirty-six-inch by ten-foot boiler, seventeen horse-power, one half of the shell would amount to fifty square feet and the tube surface to two hundred.

The portion of the shell that the radiant heat then could reach would be but twenty-five out of two hundred and fifty feet, or one tenth of the whole heating surface; *while eight tenths, or the whole tube surface, is out of the direct action of the fire.*

It has generally been conceded that one foot of heating surface *in the furnace* and *over the grate* is worth from *three* to *five* square feet of the tubes and surfaces remote from the fire. It has also been conceded that the effect of fire or heat on any body removed from it is *inversely as the square of the distance the body is removed.* If the effect at one foot from the fire is represented by 1, removed to two feet distant, the effect would be one fourth of one.



Position of the absorbing surface has much to do with the effect obtained; a figure will best illustrate this.

The fire being in the circle at the centre, the value of the horizontal surface at the top is represented by 4, that of the vertical surfaces at the sides by one-half this, or 2, and below the fire by 0. This relation also applies to the tubes of horizontal boilers, not more than two thirds of whose circumference should be taken as *effective heating surface.* I think that this is the Government rating.

The position of the internal tubes of small diameter, and overhanging the fire, are the best that can be found for absorbing the heat of slow fires and low combustion; while, with a quick, sharp fire, a corresponding effect is realized.

Time and Position. The evaporative efficiency of a given amount of heating surface depends on the *time* allowed for the passage of the heat through it, or for the contact of the hot gases. The greater their velocity, the less time have they for imparting their heat to the plates or tubes where the length of surface is limited. The velocity through a tube or flue may be increased, either by reducing its area — the total quantity of gases passing through remaining constant — or by increasing the draught, and so causing a greater amount of gases to pass through in a given time, the area of the tube being unaltered.

In 1858 Mr. C. W. Williams experimented on a small, open-topped boiler, four feet six inches long, having a three-inch tube passing through it. The boiler was divided into five compartments, the first being six inches and the rest being twelve inches in length. The heat was supplied by means of a gas burner, placed in one end of the tube, bent down at a right angle. In a trial of four hours the water evaporated from 44° was in the five compartments severally *ninety-six*, *forty-four*, *twenty-four*, *nineteen*, *and sixteen* ounces; and, although the temperature of the escaping products of combustion was 500°, that of the water in the last compartment was only 170°.

In another trial of four hours with the same boiler, from an initial temperature of about 190°, the results were *ninety-eight*, *forty-four*, *thirty-two*, *twenty-three*, *and seventeen* ounces evaporated. The temperature of the water in the last compartment fell to 170°, showing that the absorption was less than the radiation of the heat, which, however, would not have been the case had the boiler been closed in.

The temperature of the escaping products was in this case about 485°. In a third experiment the boiler and tubes were lengthened to five feet, and divided into five equal compartments twelve inches long, and a strong coke fire was substituted for the gas jet. In a trial of three hours the quantities evaporated from 50° were *one hundred and seventeen*, *ninety-two*, *seventy-three*, *sixty-four*, *and sixty-three ounces*, the products escaping at a temperature of 800°, whilst the temperature of the water in the last division did not exceed 206° at the conclusion.

If now the discharge of the smoke and products of combustion be at the top and straight out of the boiler, it will take them but half the time to reach the chimney that they would occupy were there a return draught to the base of the heater, and thus there is a less percentage of heat taken up by surfaces in contact. In the same boiler the difference between a direct and return discharge of the smoke amounted to 20 per cent in favor of the latter. Other experiments go to prove the value of time and the distance that the gases have to travel.

Connections. The manner of uniting the several sections into a common structure for unity of effect should not be passed without a word, as on this depend somewhat the uses to which such boilers can be put.

The method of joining adopted by the writer in 1870, by *nipple and locknut connection*, has been found entirely satisfactory, while being the simplest, because available for any use and pressure required, providing, also, for expansion. An evidence of this may be seen in the readiness with which it has been borrowed and grafted on to the *Gold*, *Clogston*, *Exeter*, *Walker*, *Mercer*, and several other sectional boilers that started with flat or grooved bosses, held to a joint with long or short bolts.

This improved manner of treating cast iron dispenses at once with all methods of joining and connecting sectional parts of such boilers together by means of bolts, flanges, rods, or packing to form a whole generator; such connections always proving a source of danger, trouble, and expense. In case of accident, it also permits the ready disengagement of its section, and its removal at a future time.

Construction. Whatever may be the construction of the boiler itself, the fire box or chamber immediately around the fuel should not be water surfaces, but rather surfaces which will absorb and radiate the heat into the rising gases.

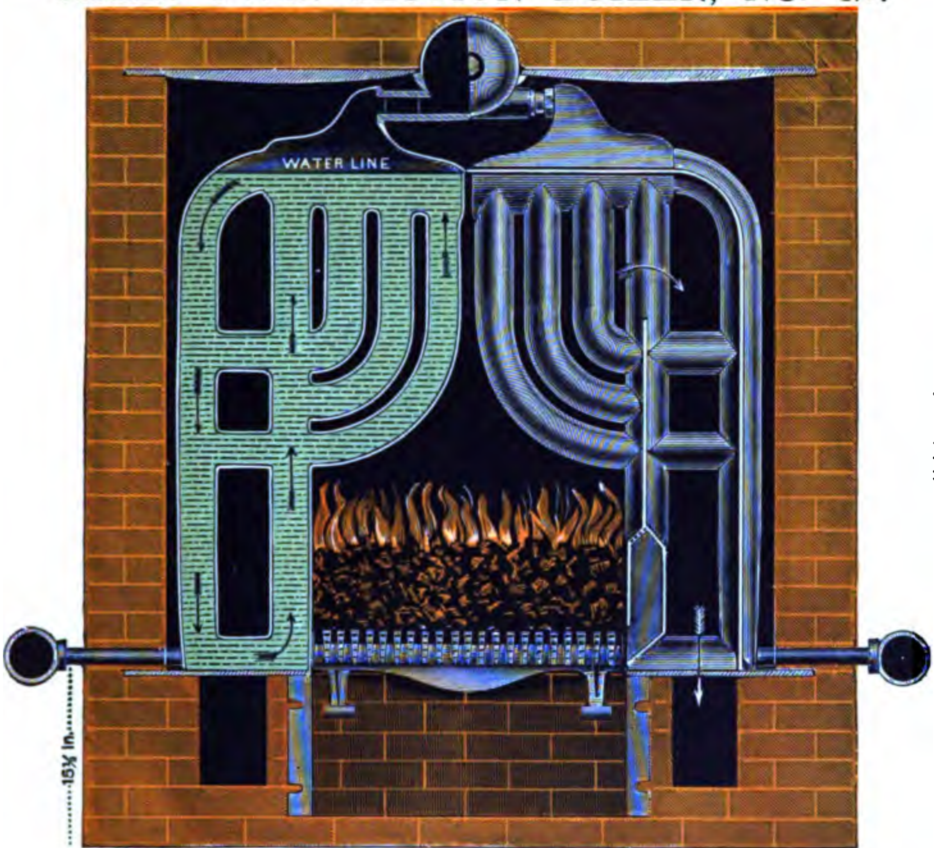
In the Mills boiler construction this reduction of the water surfaces in the fire chamber and on the fire line is accomplished by the constructions of the sections themselves, so that the real water surfaces do not touch the fire line only once in six inches, the intervening space being pockets filled in with a non-combustible substance, which also forms the joint between the fire box and the smoke flue immediately adjacent thereto.

The accompanying cut (page 275) shows this construction on a line just above the fuel, one half of the figure being in section showing the pockets formed on one side of the section, the water tubes, and horizontal flues; the other half shows the top of the pockets and the blank spaces between each section, where are the exit ports for the smoke on its *downward discharge into the horizontal chimney, beneath the boiler and on each side of the ash pit.*

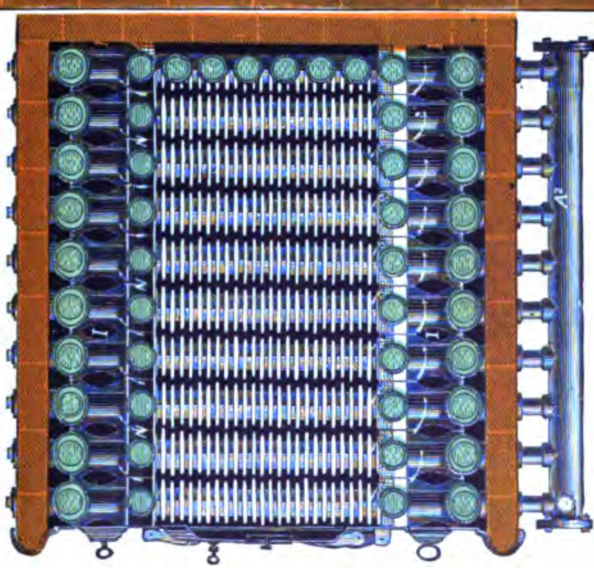
The perforations shown on the top of these pockets are for the admission of air when burning bituminous coal, or when the larger sizes, as Nos. 5 and 6, are used for power; but are always closed when the boilers are employed for heating purposes by either a steam or water circulation.

PLATE No. 15.

MILLS TWIN SECTION BOILER, No. 4½.



Height, 6 ft.



The water is inside the tubes,
the fire around them.
Draft is downward to flue below.

Each section is 6 inches across.
Weight about 350 pounds per section.
Heating surface, 16 square feet.

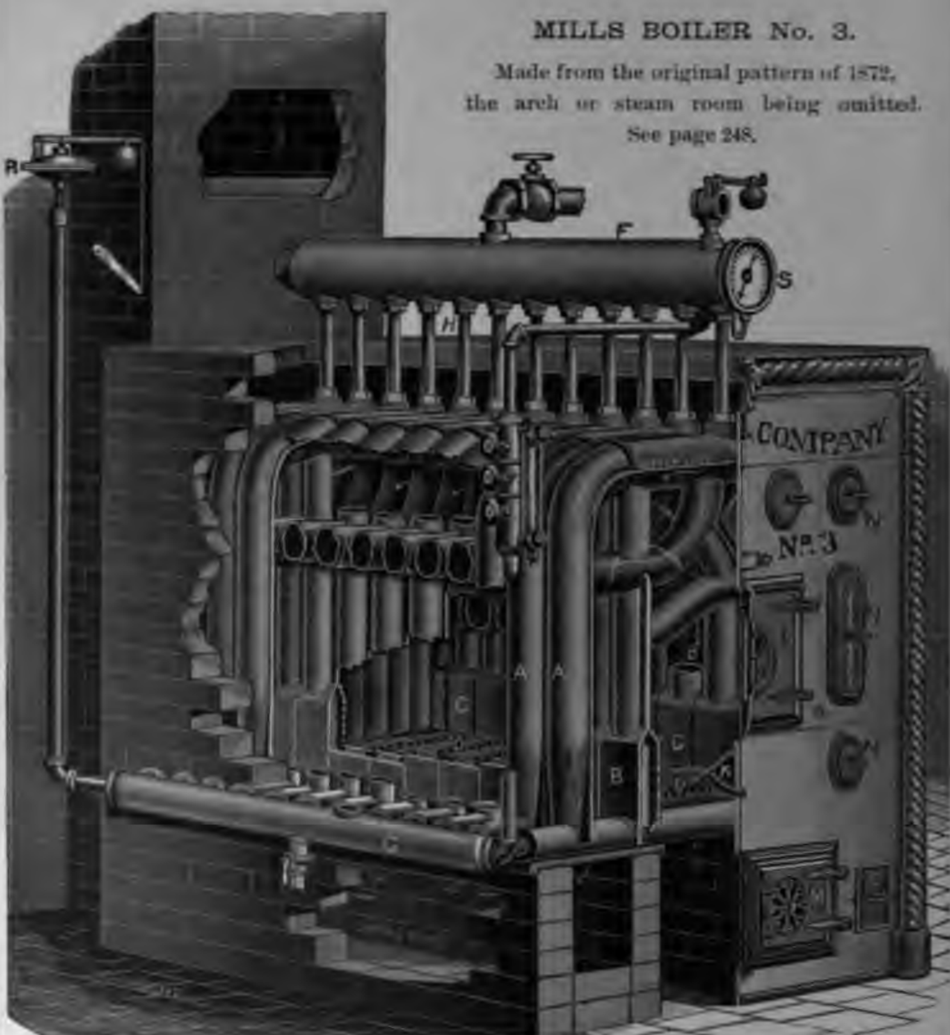
Section of all Mills Boilers above the Grate.

PLATE No. 16.

REGULAR STEAM OR WATER CIRCULATING SECTIONAL BOILER

NOS. 1 AND 3.

For other details, shaking grate, etc., see page 275.



Section A A, return smoke flues at B B.
Pockets between sections at C C.

Flow and return drum at F and G.
Cleaning doors at N N N and O.

For size, weight, dimensions, etc., see the following schedule of all sizes and weights.
Grate at D D. See also plate No. 15.

HEATING SURFACE.

Of the total heating surfaces in a Mills boiler, *three quarters* of the *whole are in the direct rays of the fire, while two thirds of the remainder are over the grate*, and the surface in the return flue on each side of the fire chamber is in close proximity to the grate, and less than one quarter of the distance from the live coals that is found necessary in other boiler constructions.

The peculiar construction of the internal and return flues on both sides of the fire box, and the exit of the spent products into what is really the chimney on the floor, is one of the best features in this otherwise desirable combination, and it no doubt accounts for the singular efficiency and economy secured. In the experiments made at the time the change was made, two years after the first construction, it was found that the difference in fuel between a discharge at the top of the section (even with two horizontal returns), and between a discharge at the bottom between each section, amounted to 20 per cent. This might be expected, since with a good fire in the furnace the temperature of the exit gases may safely be borne with the naked hand.

Not only is the general outline of this boiler vertical, but all the internal tubes are vertical; and, as the fire follows the same direction, there are no horizontal tubes or partitions to become coated and clogged with soot; and ashes, that so often lodge on horizontal tubes and surfaces, are swept along with the draft, and are found in the flues.

While, on the one hand, it seems desirable to bring the water-heating and absorbing surfaces as near as possible to the fire (in order to avail of the radiant heat rays), it should not be overlooked that the best conditions of perfect combustion and economy of fuel are not and cannot be found in *nearness of the cold-water surfaces to the fire*, chilling the rising gases, and retarding the mixture of them with the oxygen, at the time and place where they could unite, before they are swept away to the chimney and lost.

Plate 16 shows the vertical nature of the tubes and the internal water surfaces; also that, while each section is an independent structure, that the tubes composing such section are also independent in their water supply, circulation, and delivery of steam or liquid current to the common outlet, without in any way interfering with each other.

In the heating and circulation of water, this has been found to be an important construction.

Not to be misunderstood, I will state that the heating of water in separate vertical tubes which only unite at their point of exit, as at the flow drum, and where the action of the heat is culminating at its highest point, is a source of power in itself.

Next to the perfect construction of the furnace of these generators, the location of the heating and absorbing surfaces is doubtless the key to the great economy secured, since nearly all engineers and practical men are aware that one foot of fire surface (that is, the *surface on which the fire really shines*) *is equal to three feet of flue or any other surface situated at a distance from the fire chamber.*

See Haswell's "Engineer's Hand-Book," page 592.

In a wrought-iron tubular boiler the surface on which the fire shines is not one to six, while in these improved generators the surface in and around the fire chamber is three to one; and the gases, always being in full communication around the vertical tubes of the return flues, continue in full combustion until all their heat is given off to the surrounding water in the pipes.

Not so with gases forced into long tubes of small diameter, whose temperatures, being so low, render combustion impracticable after the first few feet.

From what has been already stated concerning the small amount of heat transmitted by conduction, radiation, and convection, from the transparent gaseous products of combustion, the heating surface at a distance from the furnace, in order to be effective, should be arranged to bring the gases in direct contact with it, by *changing the direction of the current, or by placing water tubes in their path;* but, at the same time, the arrangement must not impair the draught in any serious degree.

The great superiority of the furnace-heating surface, both in locomotive and other types of boilers, is, no doubt, greatly owing to the radiant heat from the incandescent fuel being principally absorbed there. According to Peclet, the proportion of radiant heat from red-hot coal may be taken as .5 of the heat of combustion. The greatest quantity of this is given off upwards, and but very little is absorbed by the hot air, except what is not taken up by plates against which it radiates, in the same manner as our atmosphere is only warmed by the earth, and not by the sun's rays which pass through it.

The evaporative value of a square foot of heating surface varies, then, in different classes of boilers, as well as in the same boiler, according to its *position*, *condition*, *nature*, etc.

In consequence of this and the uncertainty of the other conditions on which depends the evaporative power, there is considerable difficulty in determining precisely the heating surface necessary for the production of a given amount of steam in different boilers. The simplest way to estimate the evaporative power of a boiler is to take the average duty of the whole heating surface, found by experience for the various descriptions of boilers in use.

In locomotive boilers the highest average value for the whole surface in the boiler is 13.5 pounds of water from one foot of surface, or about one cubic foot of water from about four and one-half feet of surface; and in the ordinary tubular and externally fired boilers from three to seven pounds, or one cubic foot from twenty-one to nine square feet of heating surface, ranging from twenty pounds from one square foot of furnace surface to a few ounces or nil per square foot, where the gases quit the boiler.

The *average* line in table No. 7 below and on the right side shows how nearly uniform the results are when the various boilers are brought to their best performance, and under conditions where errors are reduced to a minimum.

For efficiency and economy we read:—

14 wrought-iron shell boilers, pounds water evaporated per 1 pound of coal,	10.81
5 wrought-iron or steel sectional safety boilers	11.37
10 cast-iron sectional safety boilers	11.28
The average proportion of grate to heating surface is	1.33
Coal burned per square foot of grate per hour, average, pounds	10.8
Water evaporated per square foot of heating surface per hour, pounds	2.98
Average evaporation per pound of coal, pounds of water	9.98
Average evaporation per pound of combustible, pounds of water	11.07

Experiments have been made with the Mills boiler probably every one or two years since the boilers settled down to their work.

The early tests were made by G. B. N. Tower, an ex-Chief Engineer in the United States Navy, by Colonel E. H. Hewins, and Wm. B. Allen and others.

They were made with the care and accuracy generally observed by professional engineers, and gave a duty exceeding *ten pounds of water evaporated from and at* 212° *per pound of combustible;* but, as they have been published before, we do not reproduce them here, or any of the later ones except those at Buffalo and at Springfield, made in connection with *mechanical firing and the Brightman stoker* (see page on this modern invention in the fuel section). As even ten pounds of water evaporated from and at 212° per pound of combustible is a high duty, far exceeding the average of boilers, the inventor and manufacturers have thrown off the odd pounds often obtained above this high standard, and simply guarantee the duty that may be obtained from any of the fifty different sizes made at *ten pounds*, or a *horse-power from three pounds of good coal.* The average of heating boilers will not exceed seven.

For very full details concerning nearly all the prominent boil France, England, and the United States, and evapo table No. 7 (Centennial experiments, 1876), page 265.

The main and distinguishing features secured in these improved generators and heaters may be classified as follows:—

Construction. The mechanical construction of a steam generator in one or two complete and homogeneous castings, of such form and arrangement of pipes, so grouped together, that there is no *unequal expansion or contraction of any portion;* the form and diameter of the pipes insuring the greatest amount of strength for the least weight of metal.

When shipped or set upon proper foundations, they are complete in all their internal arrangements. *The furnace, grate bars, air pockets, and flues are all formed without further trouble and expense.*

Safety. Safety is attained by the separation of the water and steam into small subdivisions, as we divide a barrel of gunpowder into squibs and crackers, which we place without restraint in the hands of children. So with this pipe and divided construction of a generator, should rupture occur, by and through any cause whatever, nothing worse would happen than the escape of the water and the steam, and the loss of the subdivision, which is merely nominal, as duplicates are always held at the foundry to replace such breakage.

Strength. It is well known to engineers and others that the tensile strength of cast iron is below that of wrought iron of the same thickness; but, when cast in small cylinders of even metal, the strength of such cylinder or pipe is far beyond anything required of it in the way of steam pressure. A section of generator No. 3, taken at random, was placed under hydraulic pressure, and showed no sign of yielding until seven hundred pounds to the square inch was indicated on the gauge.

A section of No. 2 generator, tested at the same time, sustained *six hundred and fifty pounds pressure to the square inch before it yielded, being something like three times the pressure that the best wrought-iron shells of wrought tubular boilers would endure.* See page 248.

The losses due to radiation in brick set boilers and in some of the portable sectional class, estimated at 12 per cent, are in the Mills boiler almost wholly avoided by the construction of the return flues *within the sections*, a line of four-inch water tubes *inclosing these flues*, so that the heat products of combustion do not ever come in contact with the brickwork, or whatever may be used as a covering for the outside surface; for this purpose a wire netting and asbestos may be used, and equally good results obtained.

Furnace. The construction of the furnace, by which the air is carried in separate channels, in a pure state, not only to the coal on the grate, but also to the gases in all parts of the fire chamber in such minute and subdivided quantities that chemical union immediately ensues, insuring the degree of economy inseparable from such conditions.

In most other boilers, cylindrical, tubular, or sectional, the furnace, the most vital part—the lungs, so to speak—is left entirely out by the designers and builders, to be constructed by the masons, who build, each one after his own idea; while the owner is left to select some kind of a grate bar on which the fuel is to be burned.

Water. By placing nearly all the heating and absorbing surface vertically, the water is presented in small columns to the fire, and in the most favorable condition to be vaporized, the steam also having the most perfect freedom to leave the water, unobstructed by any cross currents; while any sediment that may be contained in the water will settle in the cross pipe below the fire, where, instead of being converted into scale, and fouling the surfaces, as in other boilers, it remains in a soft condition, and may be removed by being blown off under a pressure of steam, or cleaned out mechanically through the openings in said pipe for that purpose.

Facility of Increase. The enlargement of these generators—a feature claimed but rarely possessed by other sectional boilers—is as remarkable as simple; since to remove the front, and place beside the existing generator one or more divisions, would be at the most but a day's work for any piper; while almost any man, with good common-sense, a wrench, and a pair of extension tongs, could not fail to set one up as sent from the foundry

Safety from Fire. It often happens that when the heat and smoke leave the top of furnaces and heating boilers there is a difficulty in keeping such smoke pipes a *safe distance from the ceiling and surrounding woodwork.* The building law of this and most other cities requires twelve inches space clear, and this twelve inches is often not to be had except by excavating, and setting the boiler in the pit so formed, which, by the way, is a nuisance from first to last, and one *that has no compensation either in the present or the future. A competent engineer will not require a pit for his boiler.*

Cleaning. The arrangement of the whole heating surface, with such ample room between pipes for the introduction of a steam or gas jet, renders the cleaning of the same through the openings in the front and also at the sides, in the rear chamber, from soot and all exterior deposit, an easy matter. (For tests of efficiency, see page 265.)

GRATES AND GRATE SURFACE.

Perhaps nothing connected with steam and other boiler power is of more importance than that part of the furnace which supports the coal while it is burning. For this reason much attention has been given to the size, shape, and arrangement of grate bars, and many patents have been granted for supposed improvements.

Some of these latter have been put on trial, some have remained, but many have disappeared, proving that they had but little advantage over the ordinary flat stationary bars.

It has, however, become a conviction among engineers and firemen that the old method of cleaning fires on the flat grates by means of the slice bar, poker, and hoe are not only crude and laborious in the extreme, but wasteful as well. The opening of the fire doors fills the furnace with cold air and chills the fire and the boiler surfaces, thus retarding the production of heat for a considerable time after each operation.

This whole matter has received attention under the head of mechanical firing; but often so radical a change cannot be decided upon, as for many of the heating boilers and furnaces it is not practical. The shaking grate seems the next best substitute, as by this simple means the cleaning of the fire is effected from the outside and while the fire doors are closed, avoiding the chilling effects to the fire and heating surface referred to, while the labor is so reduced as to be performed by a child or maid-servant.

The cross-sectional arrangement of portions of the grate surface rotating on trunnions seems to be the favorite idea, and apparently has been re-patented a dozen times in the last ten years, as nearly every form of this arrangement will be found to bear a later date.

The writer first used this arrangement in 1871, and it was shown in a Mills boiler circular issued by Geo. W. Walker in 1872.

It was not then mounted on *trunnions*, as at present, but encircled the cross pipes uniting the lower legs of the sections. The form or curve of the upper surface of the teeth is changed, while only one half of the bars are rotated from one side, reducing the labor and increasing the cleaning effect and general efficiency.

Mills shaking grate, 1872.

It is now known as the Reed grate, and under its changed conditions and new name it has won much favor, having been put into Gold's and Mercer's boilers, also made at Westfield.

See cuts of boiler and the latest arrangement of this grate, page 275.

SIZE AND CONDITION OF THE COAL ON THE GRATE.

While on the subject of grates and their relation to the low pressure and house-warming furnaces, it seems proper to note the effect of the *kind* and *size* of coal employed, as on this, perhaps, more than on any one other thing (except the chimney) depends the efficiency, and often the ultimate success of the heater.

In all our review of fuels and combustion, Part I., it was noticed how much stress was laid on the mixture required between the fuel and the air supporting and perfecting combustion, and that finally the best possible effects were reached as the fuel became smaller and smaller, until it reached the sizes of "nut" and "slack,"—reference being had to the mixture above noted with atmospheric air. (See chapter on the Construction of Furnaces, pages 93 to 120.)

Large coal, furnace and egg size, requires, first, a strong draught, not often attainable in house chimneys; second, a greater depth of coal on the grates, to prevent the air passing uncombined; neither of these last requirements, when attainable, are conducive to economy.

A medium or small egg, or even stove size coal, although costing a little more, is preferable, and many a house heating apparatus would have proved a failure but for the saving grace of small coal, as through it no air passes uncombined; such a fire is not often seen dead along the outer edge. This condition is proof positive of incompatibility, either in the fuel or in the flue.

In discussing this matter lately with one of the most practical and observing steam furnace men, Mr. John R. Reed, of Westfield, Mass., he expressed substantially the views given above, and further said that, when called to see furnaces that did not come up to the requirements, it was one of the first things to which he gave his attention—the chimney and the size of the coal; if either of these had not been carefully considered, success in general results was not to be expected.

We have room here for but one other caution—don't try to run a dirty fire; free your grate from ashes and waste material, whether you require the full power of your furnace or not; *clinkers are a common but unnecessary result of a dirty fire*, sometimes the result of being obliged to carry too much draught on too small a grate area.

The whole question of fuel for the dwelling is of the first importance; the large first cost in eastern States of fifteen to twenty tons of coal at $6 or $7 per ton, with the excessive labor involved in getting it into the furnaces and the ashes out, proves nearly the last "straw" on the poor man's back.

OFFICE OF

ALBERT B. FRANKLIN, WARMING AND VENTILATING,

NO. 228 FRANKLIN STREET.

BOSTON, March 2, 1889.

JOHN H. MILLS, ESQ.

My Dear Sir: In reply to your inquiry as to my experience with and consequent opinion of the Mills safety sectional boilers, I will say that, of the many boilers I have seen and handled, I have yet to see a more safe, efficient, durable, and economical steam generator.

I have been acquainted with these boilers since 1875, and have used them personally some five years without a single serious accident. They are easy to handle and to manage.

I am using these boilers in a large number of *school, church*, and *office* buildings, both for *water* and for *steam*, and with excellent results. The question of safety is sometimes thought of, but is not given the prominence that this subject demands.

I have just now reason to be thankful that I persuaded one of my customers to use a Mills safety boiler in place of a horizontal tubular pattern for his block of stores at Melrose.

Last Saturday evening I was called to a boiler that was in trouble. Upon examination I found two sections broken. It happened in this way: The water was low —"out of sight"—and the owner thought that he could "open the valve, and let in the water slowly," without drawing his fire, which was a hot one. The result, I have stated, was the breaking and cracking of two sections.

By disconnecting the broken sections from the others, and plugging the steam and water drums, I was able to have the fire started again in a few hours, and so prevent loss from damage to the plumbing by freezing, for the accident happened in zero weather; and the ability to do this, I consider another good point in favor of cast-iron sectional boiler construction.

Had his boiler been of the dangerous type,—a shell boiler, before spoken of,—I tremble to think of the consequences. The recent explosion at Hartford is an example of a result that I do not wish to have even a remote connection with.

In this relation I think it proper to state that the evident remedy for all the dangers and uncertainties of steam as applied to heating buildings, lies in a change of medium, and in the substitution of *water for a steam circulation.*

We are now doing this extensively in all classes of buildings, and find the Mills boilers the best adapted for that purpose.

Have just placed two of them, No. 5, in the Elliot Congregational Church at Newton, Mass., including the Mills system of mechanical ventilation.

I remain, yours very truly,

ALBERT B. FRANKLIN.

BUFFALO, Aug. 20, 1883.

TO WHOM IT MAY CONCERN:

This is to certify that, when making our arrangements for warming the Baptist Chapel on Delaware Avenue, we examined several kinds of steam-heating apparatus, and finally adopted that made by Mr. John H. Mills, of this city. The heating is accomplished by both direct and indirect radiation, the indirect being in chambers below the main floor supplied with air from without the building for ventilation. The direct radiators are all placed at the sides and below the windows. The vestry is also warmed mostly by the supply and return lines passing through.

After a winter's use, both before and after the building was completed, and having tried the boiler both with and without water, we are convinced that it is perfectly safe under treatment that would destroy a wrought-iron boiler, if not the building. The whole apparatus is simple, silent in operation, and efficient.

Thos Chester

E L Hedstrom

ST. CATHERINES, Aug. 17, 1883.

J. H. MILLS, ESQ., BUFFALO, N. Y.

Dear Sir,—This is to certify that in the fall of 1877 you erected the steam-heating apparatus in the First Presbyterian Church in this city, using one of your No. 4, 10-section Safety Boilers.

The heating surface is placed in the pews under each seat in three separate sections, the supply and return pipe being placed underneath the floor line, and all controlled by valves placed near the boiler, there being no vents or valves of any description in the auditorium.

The heating surface is ample to thoroughly warm the building in the coldest weather, and is perfectly noiseless in its operation; the fire is not commenced until Sabbath morning, from six to eight o'clock, according to the temperature of the weather, the coal consumed each winter being about nine tons, being very much less than the trustees expected.

The church is only in use on Sabbaths (morning, afternoon, and evening), and occasionally a meeting is held during the week.

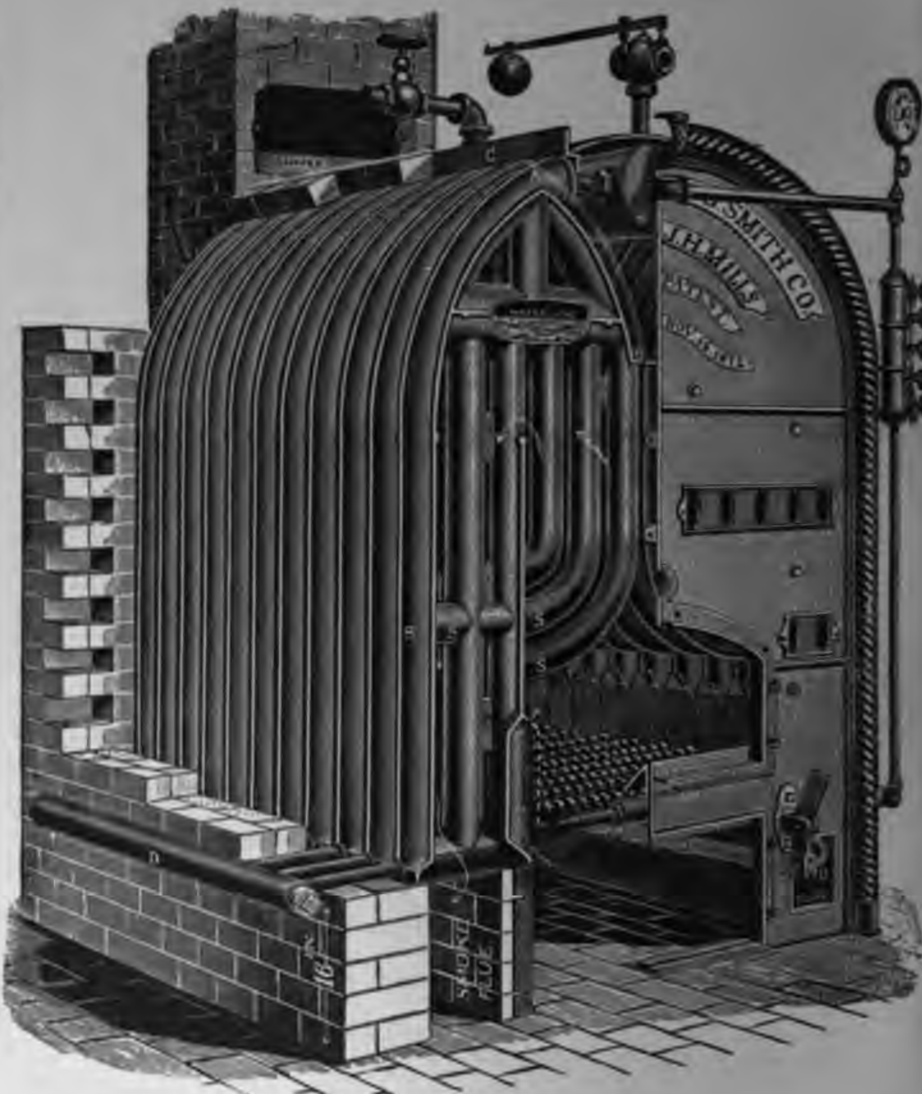
So far it has given entire satisfaction, has required no repairs, and is very easily handled, being in charge of the sexton.

L. H. Collard. Treasurer
of Board of [illegible]stees

PLATE No. 17.

THE MILLS TWIN SECTION SAFETY BOILER, No. 5,

FOR STEAM AND WATER CIRCULATION.

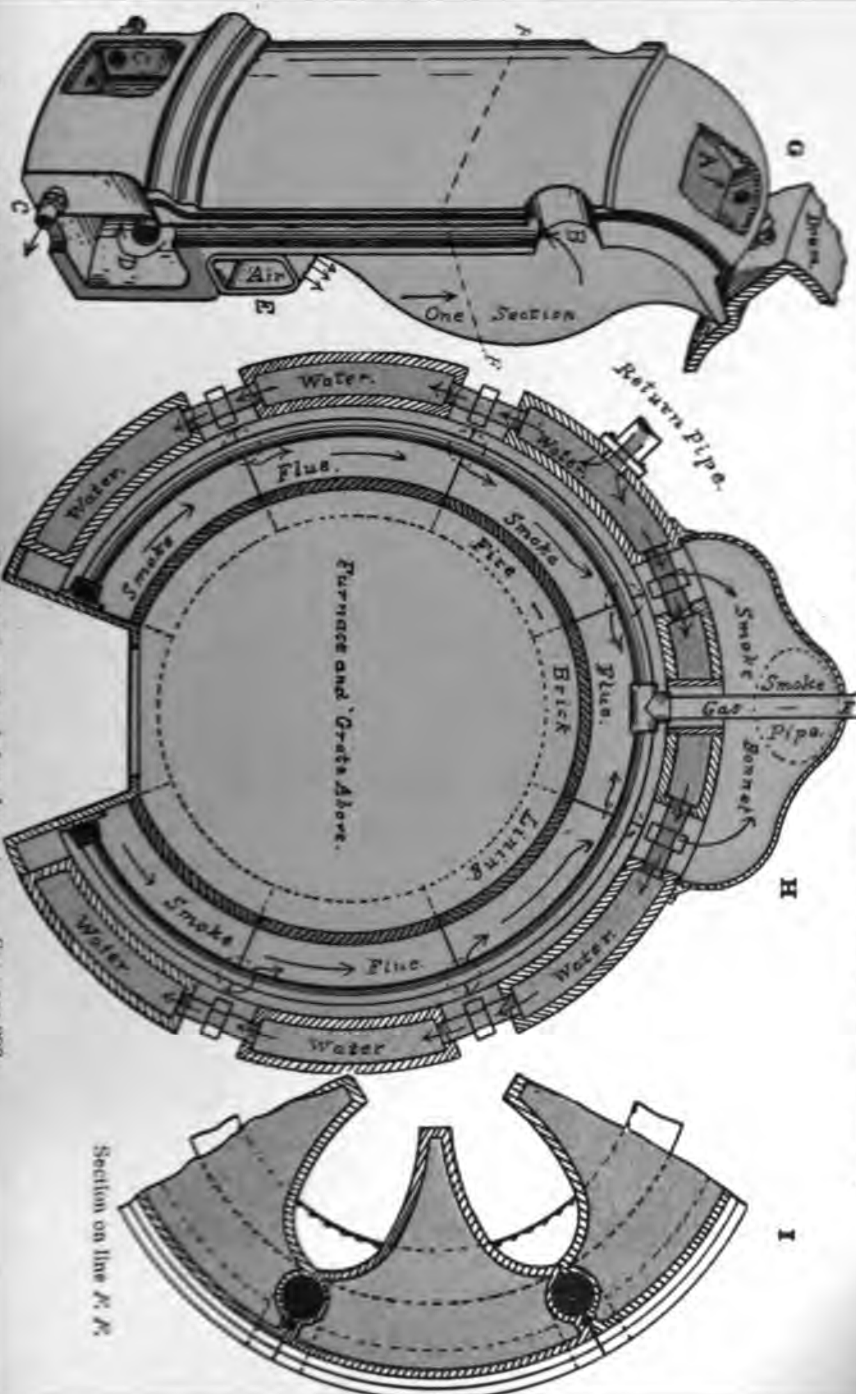


This boiler is adapted to supply high pressure steam for engines, pumps, and elevators.

See letters of Wm. A. Sweet and Hancock Inspirator Company, page 251, and experiments, page 265.

PLATE No. 16½.

SECTIONAL VIEWS OF THE MILLS PORTABLE WATER BOILER. (See Plate No. 18.)



One complete section.

Horizontal section, below the grate. See page 290.

Section on line F. F.

*THE BOLTON COMBINATION WROUGHT AND CAST IRON BOILER.

A peculiar and interesting form of pipe boiler is shown on the following page. This boiler consists of a cast-iron top and base, connected by a row of wrought-iron pipes at each side, and a row rising from the back, extending horizontally forward above the fire, and then upward to the front of the top-water chamber.

What is perhaps the most noticeable feature of this boiler is a system of pendent water pipes, occupying the entire space above the fire. The accompanying cut shows the construction of the pendent pipes. The open, upper end screws into the top-water chamber; *the lower* end is welded to a point.

Within is a circulating tube, open at both ends, extending the full length of the pipe. When in operation the water in the pipe outside the circulating tube, being presented directly and in small volume to the heat of the fire, is quickly heated and rapidly rises, its place being supplied by a downward stream through the inner circulating tube. Each pendent tube thus constitutes a distinct auxiliary circulation. This device is well known in steam generators, for which work, however, it is less effectual.

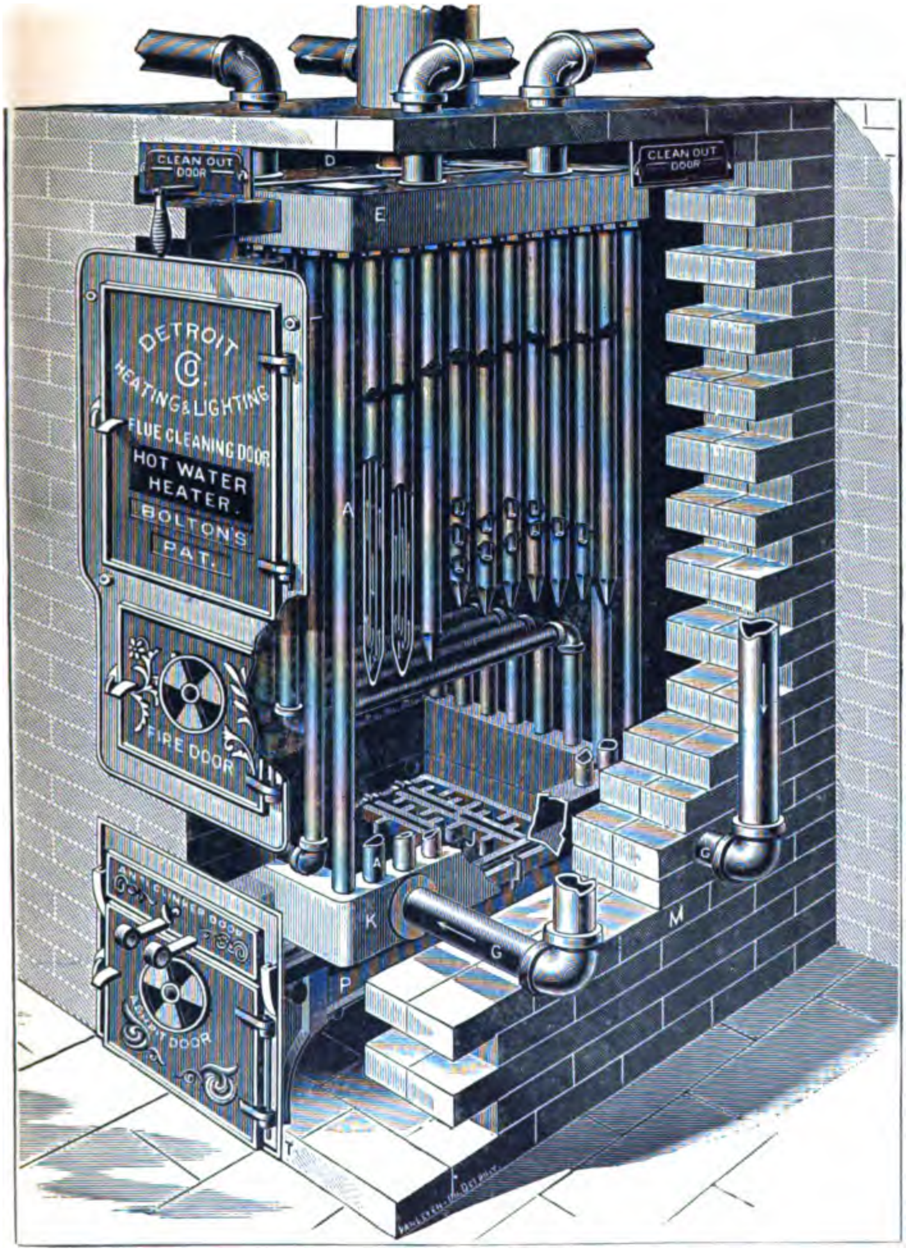
The value of a heating surface may be measured by the difference in temperature between the fire on one side, and the water on the other. The greater this difference, the more rapidly does the water absorb the heat of the fire, and, conversely, the less this difference the more nearly is the value of the heating surface neutralized. It is manifest that this difference in temperatures is much greater in the hot-water boiler, where the water seldom touches the boiling point, than in a steam generator, where a relatively small body of water is kept constantly far above this point, and consequently many degrees nearer the temperature of the fire.

Superior durability is claimed for this construction, and freedom from leaks, all the parts being screwed together, with no *bolted, flanged*, or *packed joints;* its great efficiency, due to its extensive fire surface, and vertical circulation; also the brick casing, in that it conserves and utilizes the heat, which uncovered boilers waste by radiation in the cellar. This will be referred to later; also the value of vertical pipes as heating surfaces, when employed in circulating *water* instead of *steam* for warming dwellings and public buildings.

* See pages in Appendix for notice of the Detroit Heating & Lighting Co., Detroit, Mich., and Chicago, Ill.

VIEW OF BOLTON HEATER.

BROKEN OUT TO SHOW CONSTRUCTION.



MANUFACTURED BY THE

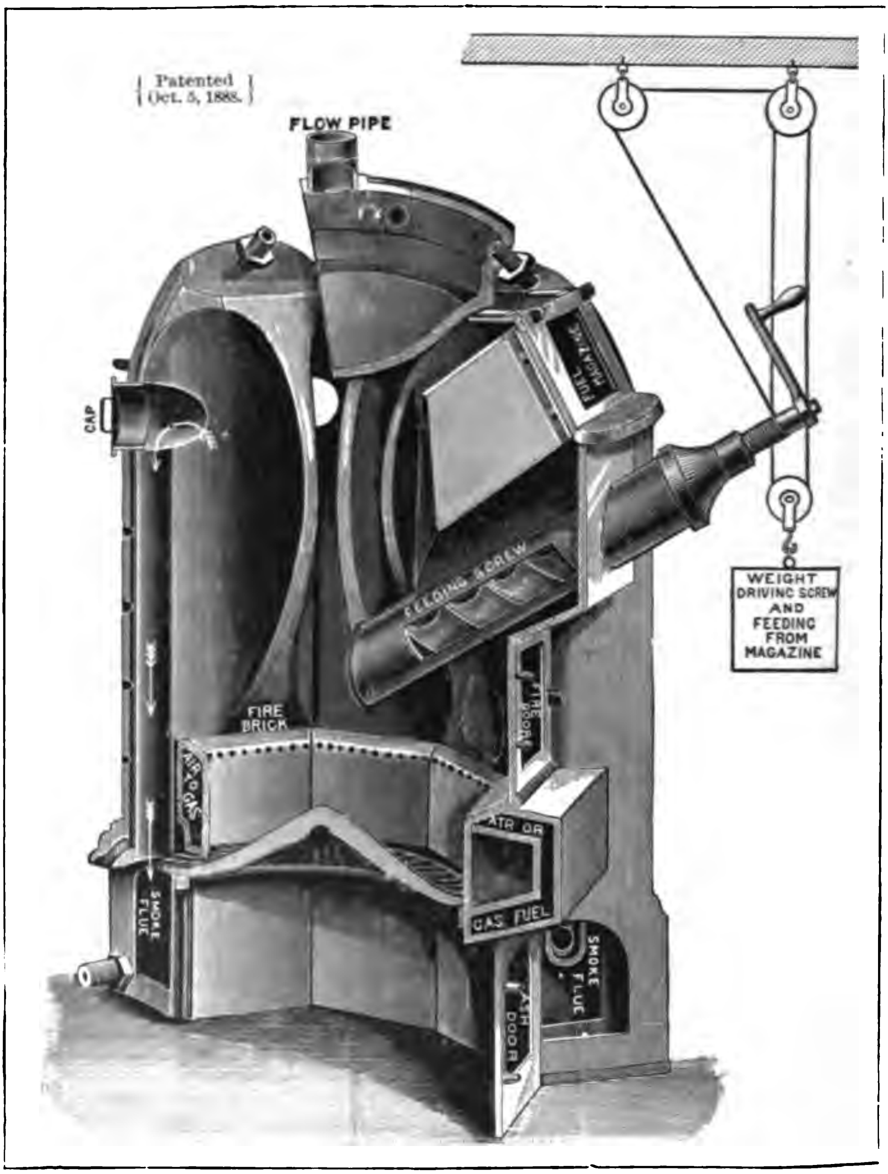
DETROIT HEATING & LIGHTING CO.,

DETROIT, MICH., and CHICAGO, ILL.

PLATE No. 18.

THE MILLS NEW PORTABLE WATER BOILER.

DESIGNED TO BURN SCREENINGS, HARD OR SOFT COAL. ALSO, GAS OR OIL FUEL. (See also Plate 17½.)



If the Magazine is filled with any kind of fine fuel, it will not run into the Furnace faster than the screw regulated by the weight will allow. A pendulum not shown governs the speed of the screw, and so the amount of fuel supplied.

VERTICAL WATER CIRCULATING BOILERS AND HEATERS.

As all the Mills boilers are practically of the vertical class, some further reference to these may be desirable, especially as all the "heaters," so called, now being rapidly multiplied, are necessarily vertical, to economize room and to admit of a magazine for holding fuel to piece out their limited grate area.

The same construction of *vertical internal return flues* is incorporated in the new Mills portable heater, with this further addition, that the absorbing surfaces are extended to the floor, thus securing the inside of the ash pit as heating surface, and rendering no foundations necessary. This valuable feature is also seen in the Gurney boiler, new series, shown in the following pages.

* While the new Mills boiler is intended to burn the fine slack and waste coals, to be bought at one half the regular prices of stove, nut, and egg coals, it is also intended to use gas for fuel, the pipe for which is seen entering the rear, and, passing around through the smoke passage, to and into the fire chamber at the front. By this means the gaseous or liquid fuel will be raised in temperature by the waste gases, and be in better condition to combine with the air (also heated) *in the mixing chamber seen in the front between the doors.*

There is no question but that an automatic supply of fuel to house and other heating boilers is a desideratum, and one that in some way must be met; and that, when properly arranged, a large economy of fuel and attendant labor will be the result. Certainly the liquid and gaseous forms of fuel, now so plentiful in the Middle and Western States, offer inducements to the inventor. Where natural gas is available, no invention is needed, except to avail one's self of the machines for mixing, burning, and controlling the pressure. Omitting the first,— a proper mixing of the gas or any other fuel with the oxygen of the air, — neither success nor satisfaction will follow, and for that reason we have given such prominence to the science of combustion in the first and introductory pages.

The larger portions of vertical heaters are, however, of cast metal, in the form of horizontal sections, laid one over the other, and bolted together to form fire, water, and steam passages, the outside not being encased with sheet metal or a non-conducting and non-heat radiating substance.

That this general and sectional construction should have advanta[illegible] is apparent from the many imitations of the first types that now [illegible] upon the market, and claim superiority from some trifling [illegible] arrangement of minor details.

* This new boiler or heater is not yet on the ma[illegible]

Many of them, however, have to contend with defects of construction and arrangement of heat-absorbing surfaces; since, in any small boiler with slow combustion and low general temperatures, the heating surfaces not in or above the fire chamber become of very uncertain value.

This and the reduced value of some other remote surfaces contribute to deceive both the manufacturer and the purchaser, the result being that, in nine cases out of ten, the heaters are credited with a power that they do not possess.

In this connection, however, and referring to the general construction of portable heaters, the method of arranging the heating surfaces, and in securing a circulation from one section to another is important. Most of these heaters and several small boilers are constructed of flat, horizontal sections, having slats or holes cored vertically through them for the passage of the products of combustion to the flue. They have also other openings for securing communication internally from one to another; but, singularly enough, these are sometimes on opposite sides, so that the water, warmed below in, say, the first section below the grate, passing into the next, must flow horizontally across to the opposite side to find an outlet into the next section, and so on, thus making in effect a *trombone coil of a vertical heater*, and thus doubling or trebling the *distance of the water in reaching the flow pipe*. It is in effect a drag or brake interposed in the circulation, which must be overcome by the heat as best it may.

In many of the older sectional "Heaters" and in most of the new ones, the manner of joining the sections at the points where the circulation takes place is generally on flat surfaces, drawn and held together by a *long bolt*, passing outside them all from top to bottom, not always in a straight line, but often at a distance from the joint thus sought, to be effected by the strain put upon *one rod held to its work by a single nut*, requiring in most cases a packing of some kind between the surfaces thus brought together.

The importance of a substantial joint, uniting sectional boilers, must not be overlooked, since even in warming operations it is often desirable to carry moderate pressures; and in the use of a water or liquid agent, instead of steam, the higher temperatures can only be obtained by a pressure on the boiler due to the temperature; that is, after passing 212°. That pressure is one of the elements to be considered and provided for, is apparent, when we consider that the whole range of temperatures in a modern (closed circuit) apparatus is 300°, *and that the boiler pipes and radiators are more or less efficient, in proportion to the temperatures of the circulating medium.*

This matter will be more fully treated in the chapter on heating mediums; it is referred to here because parties intending to use the *closed circuit* advocated by the writer should consider the *joints* in the boiler and radiators they intend to employ, because if a purchaser submit the "house heater," as it is called, to pressure not intended by the manufacturers, they (the purchasers or users) are really to blame, if rupture and damage follow.

It is fair to say that such a joint suffices for most of the heaters to which it is applied, since their projectors did not intend them to bear strains common to boilers of wrought iron, or united by a more substantial method.

Probably the most of the small heaters are intended and will be employed with an open circuit or expansion tank, in which case their joints and general construction are ample for their needs.

In this class of fire-box heaters, there is generally a condition *fatal to economy*, a small fire area surrounded with a large water surface, the three sides of the furnace being generally *continuous water surfaces*, and thus of so low a temperature as to *forever preclude proper combustion of the fuel in contact with them.* There is a notable exception to this general defect in heaters of small furnace area, which may be seen in the construction of the Gurney and Mills heaters. In these the water surfaces around the fire are *reduced*, and the space or recess thus obtained is filled in with a removable fire-brick or iron lining, the lining itself being protected from destruction by being in contact with the water surface back of it.

The lining for high temperatures is as necessary a condition of combustion as air is when forming its supporter; this is seen in the latest gas-burning lamps. These pre-heat both the gas and the air.

THE GURNEY WATER BOILER.

In nothing is this improved fire chamber more conspicuous than in the construction and arrangement of that most important part — the grate. In many small or portable heaters, the grate is a clumsy affair, hard to work, and hard to get in or out of the ash pit when repairs are made.

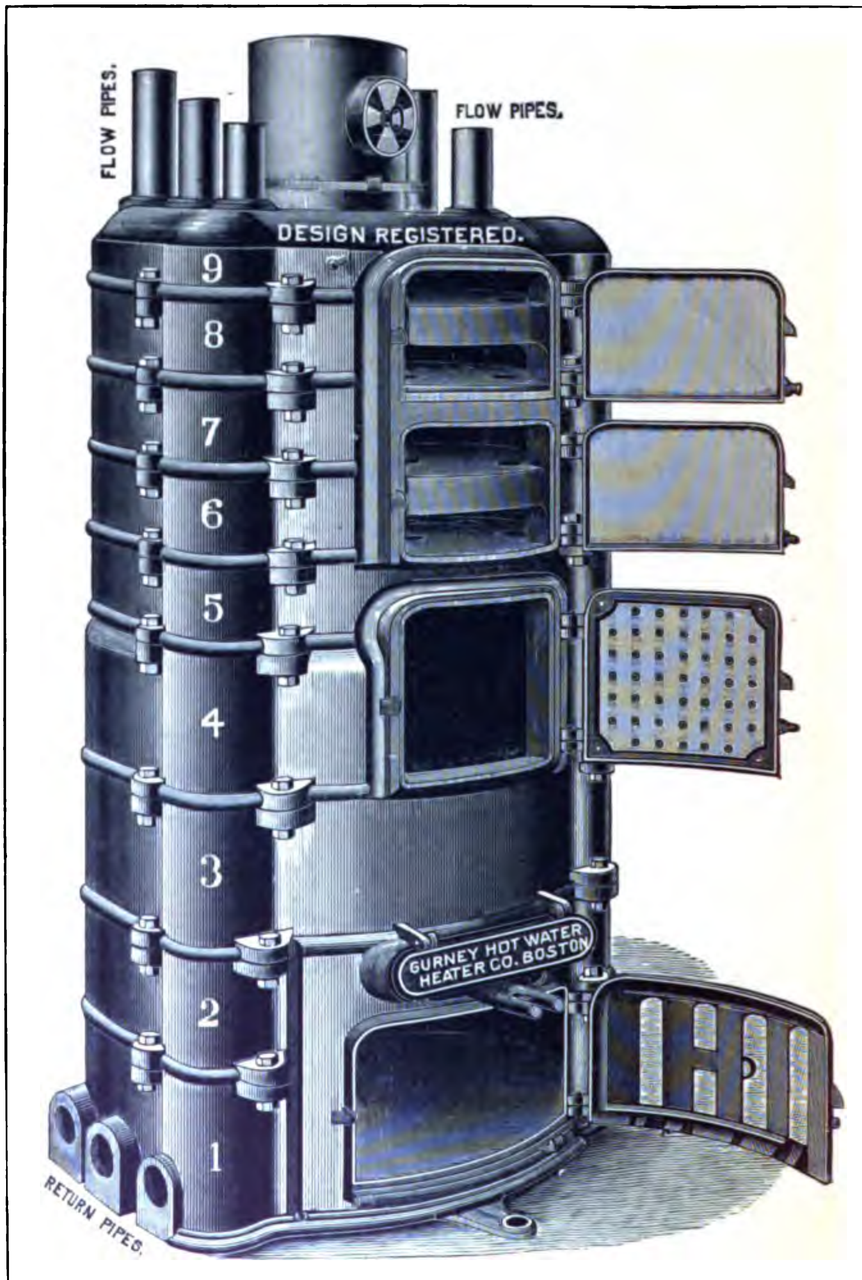
This grate is mounted on friction rollers, and is thus easy to shake; while the trap or slide at the centre enables the fire to be dumped without labor, and clinker removal, without disturbing the rest of the fire; in short, it is an ideal machine in all its arrangements for either feeding or cleaning the fire.

The grate being the most vital part of a furnace, and liable to require repairs and sometimes removal, provision for such change is essential as the first construction. In the Gurney furnaces this has not been forgotten, as is seen in the large ash pit, door, and other details.

PLATE No. 19.

THE NEW GURNEY HOT-WATER SECTIONAL BOILER.

NUMBER ONE HUNDRED SERIES, 1888.



Elevation showing Side View and Method of Bolting the Sections together.

PLATE No. 20.

THE GURNEY HOT-WATER SECTIONAL BOILER.

SHOWING TOP SECTION WITH HEAT DEFLECTOR.

Also, Water Section extending to Floor, below and under the Grate.

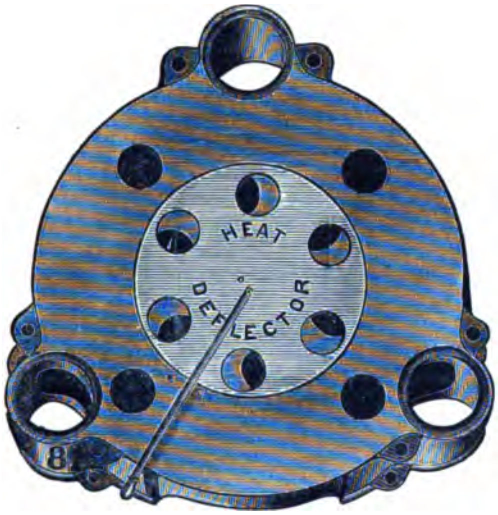


Figure 1.

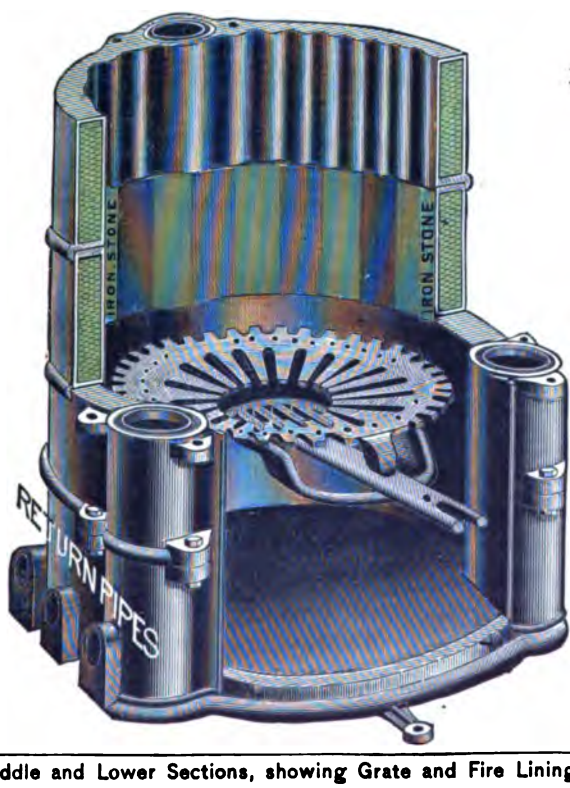


Figure 2.

Middle and Lower Sections, showing Grate and Fire Linings.

There is another feature in this boiler — I think so far possessed by no other — which, although of the first importance in a water circulation, has not been noticed by the *professional* writers.

The extension of the water chambers from the usual grate line to and over the floor, while affording a much needed protection from fire, and absorbing some of the radiant heat usually wasted there, is really of the lesser account, the greater advantage being the increased power *derived from lengthening the vertical height of the heating surfaces.*

The total power of water boilers to overcome the friction of their circulation pipes *is the height or head available between the flow and return lines.* (See Vol. II., Chapter XXIII., pages 421, 422.)

The difference of temperature between the flow and the return, *together with the height of the two columns*, is the factor of power available to flow the water to a distance and return it promptly to the heater. There is another source of power which we will refer to later.

By inspecting the sectional cut on page 297, we shall notice a dotted line at the right lettered A, B, C. Supposing the whole height of the basement to be seven feet, and the distance from A to B to be only one foot, then the increase of power in any event will be one seventh, or over 14 per cent, and the work done in a given time by the radiators will be increased by a like amount; and this oftentimes would be the whole question as between success and failure.

As the whole power available in a water circulation carrying radiators, on or below the first floor, may be represented by a head of water equal to one inch high, it is easily seen that any construction that reduces or increases this small motive power is of the first importance.

As this whole matter of a water or liquid circulation will be taken up later, we do not follow it further here, except to note that the last Mills boiler (page 290) has the same extension of water surfaces to the floor, and for the same reason.

Having devoted considerable time and space to this representative heater, we pass to some considerations that bear alike on all classes of portable heaters, of which the "Gurney," "Perfect," "Spence," "Page," and "Auburn" are examples.

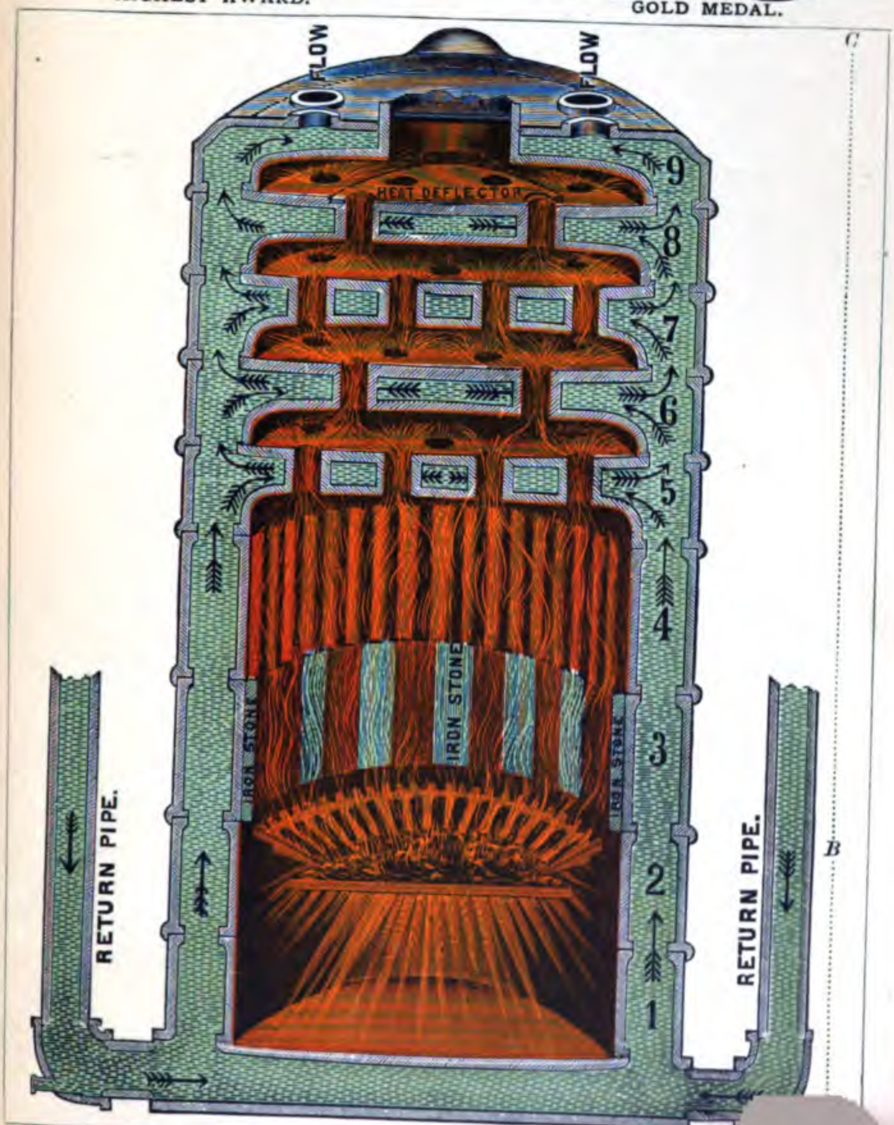
In the matter of *efficiency* the manufacturer, agents, and the purchaser are equally interested; and, as our effort is not the elevation of any one machine at the expense of all others, but the clearing up of the whole subject, we make no apology for criticising freely what appears to be general defects of construction, or, what is quite as bad, the general over-estimate of the combined value in any one construction.

Continued on pages 300, 301.

PLATE No. 21.

GURNEY'S NEW PORTABLE HOT-WATER BOILER.

HIGHEST AWARD. GOLD MEDAL.



Sectional Elevation, showing the New Water Base.

The cuts on the following page show another prominent and efficient water heater. It is called the "Perfect," and in many respects it seems to deserve its good name.

In the general construction and mounting of the sections one above the other, the action of the fire through them, this heater resembles the Gurney, Spence, Page, and several others.

But here other comparison ends, as the water-ways and connections between the sections are different. Instead of seeking direct passages for the water, the circulation is made continuous through each section, backward and forward from front to rear (as in a return bend box coil), and thus the whole body of water moves together from the inlet or return to the outlet or flow, as seen in the right-hand sectional view.

This peculiar circulation would not at first sight appear the best, or as having the minimum of friction; but the water certainly does get hot, and moves rapidly over the absorbing surfaces. The fact that the fire passes the water chambers at right angles to the circulation may have much to do with the result. The heating surface obtained by the slots through the sections is large and favorably situated to absorb the passing heat; this is clearly shown in the two views of the boiler and the sections.

The lower right-hand view shows the patent shaking and dumping grate, also the fire-brick lining and the first water section above the fire.

The recent and growing demand for small house heating apparatus, and especially that embodying a water circulation, has stimulated the production of numberless new devices and the re-vamping of many old ones that had seen their best days in other lines of work. The two heaters shown probably represent the best in the line of the new goods, although there are others that have points of excellence and desirability.

* The *Mercer* boiler and water heater is one of the latter improvements. This heater is a reproduction of the famous Gold's boiler, by a practical heating engineer, who has had much practical experience in the line of steam construction and application.

One of the best features of this improvement is covering the outside of the boiler, which is usually a load on the heating surface. The loss of economy is not the only drawback, for there is a *loss of power if the water is chilled before it gets fairly in circulation.*

Concluding, we may note that the efficiency of various boilers and heaters is substantially as follows: —

POUNDS OF WATER EVAPORATED FROM ONE POUND OF GOOD COAL.

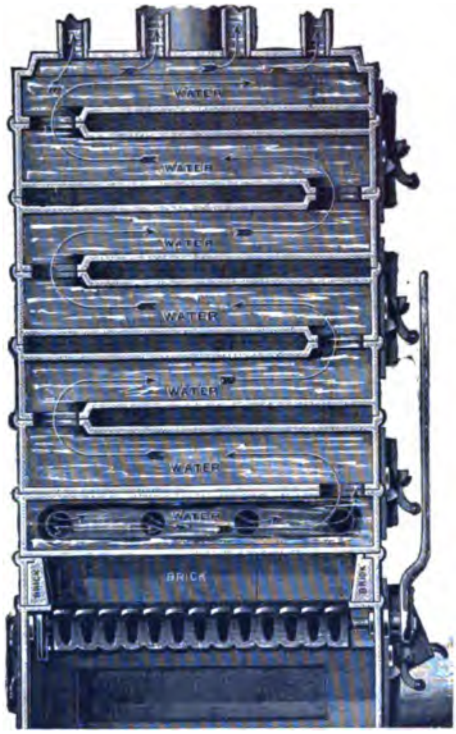
Portable heaters of all kinds, *uncovered*, with upward draught	5 to 6
Similar boilers, brick set, taking smoke off at the top	7 to 8
Same boilers, brick set, but returning smoke to the base	8 to 9
The larger sizes, with quick combustion	9 to 11

See table No 7, page 265, also table 22, for other proportions of heating apparatus.

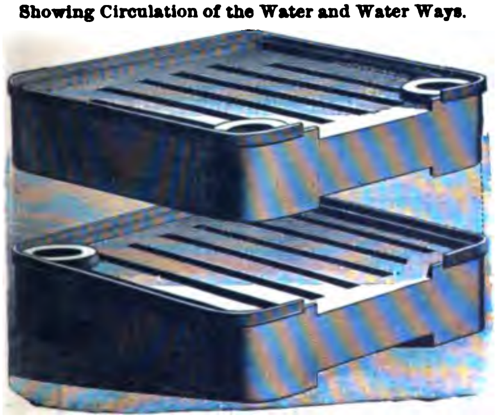
PLATE No. 22.

THE "PERFECT" WATER HEATER.*

Showing Circulation of the Water and Water Ways.



Sectional Views of the "PERFECT" HEATER.



*** RICHARDSON & BOYNTON CO.,**
232 WATER STREET,
NEW YORK.

FOR SALE BY
ALBERT B. FRANKLIN, WARMING AND VENTILATING ENGINEER,
228 FRANKLIN ST., BOSTON, MASS.

Will burn HARD or SOFT Coal.

"Perfect" Clinker and Ash Freeing Grates.

In the now more considerable demand for small heaters, the people who make, sell, and handle them are, in a measure, considered the representatives of hot-water work and its general application. Yet if their education is limited to their experience with their own constructions, they are liable to advocate a wrong schedule or estimate as the right one; and, when the result is a failure, it stands as a failure for the system which they employ.

That some of the people who are running foundries and furnishing the castings for these portable heaters are also acquainted with the practical application of heat, is perhaps true, and that their suggestions are valuable to those who desire to handle their special devices.

A pound of iron in a square foot of heating or grate surface is worth no more to-day than it was twenty years ago in the same combination. Neither is it possible to make any new arrangement of grate and absorbing surfaces that, by the *reduction of the latter, will increase the efficiency of the former;* the contrary effect is certain to follow.

That some of these new water heaters have good absorbing and distributing surfaces, is clear from the efficient work they do; but it should not be expected, either by the manufacturer or the purchaser, that a foot of boiler or radiator is likely to take on any new and enlarged value because made at any particular foundry.

The proportions of grate and heating and radiating surfaces to insure economy of fuel combustion were established long ago, and cannot be materially reduced without a *corresponding reduction in economy.**

That many people purchasing a portable heater and adopting water as the circulating medium have been disappointed, is true; and that this will continue to happen, is more than likely. Were it not for the intrinsic merits of a water system, it would not be possible to carry out the programme and schedule laid down by the manufacturer and agent for these portable heaters. Change the system of absorbing and distributing heat to a *steam* generation and distribution, and these limited proportions of heating surfaces would not stand a single day; and as it is, only harm can come to the reputation of the manufacturers or agent and to the value of a water-heating system, by a misunderstanding of the problems and the service required, or by refusing to provide for them.

NOTE.—In justice to the Gurney people, I should say that they are making a practical effort to prevent their agents and purchasers from selecting too small heaters to do their proper work, by calling attention to the uncovered supply and return lines, and that they represent 25 per cent of the whole load put on the heater.

If now we add 10 per cent more for outside boiler surfaces, we have 35 per cent of useless load imposed, and, it is safe to say, a corresponding amount of loss in efficiency on this already limited heating surface.

*See pages 282, 283.

As there is a standard by which the heat-absorbing surfaces in all kinds of steam generators are measured, it seems desirable to refer to it and the relation which it bears to water-heating and absorbing surfaces.

Owing to the later introduction of these water heaters, it is not likely that any practical tests of their intrinsic value have been made; and, from what we see and hear, it is not likely that their designers will be the first to institute practical tests, preferring rather to trust to their power of description on the enormous heating value of their various devices and the special applications of them to Mr. Smith's and Mr. Jones's houses.

Now, this is well enough in its way; but it is really nothing to the practical man and engineer, because there is no certain and recognized data by which to check the work claimed to have been done. He does not know how much heat was abstracted from the coal, or *how much was sent up the chimney for want of surface to absorb it.*

What is requisite to know is, how much water can be heated any number of degrees with a pound of coal. The circulation of the water in pipes, the effects of such heating on rooms of different exposures and requirements, are entirely side issues to the question of the *real efficiency and economy of any particular heater.*

To estimate the duty or efficiency that should be expected of this class of water-heating apparatus, we may compare it with that of a steam boiler for like uses.

The duty of a square foot of fire surface is fairly well known. In large steam boilers the evaporation (from and at 212°) is from 2 to 3 lbs. per foot per hour. In a *low-pressure* boiler it would not exceed 2 lbs., from the temperature of the return, 180°, this would represent about 2,000 *heat units.* (See table No. 7, page 265.)

A square foot of fire surface in a *water circulating boiler,* raising the return water from 160° to 200°, is then 2,000 ÷ 40° = 50 lbs. of water heated per hour 40°.

But the efficiency of the surfaces in a *water* boiler are greater than those in the *steam* boiler, due to their average lower temperatures. *This is proportional to the square of the differences between the temperatures in the furnaces and those of the absorbing surfaces.* (Rankin.)

As confirming this estimate, see page 441 and page 447, on the comparative efficiency of steam and water surfaces. *Heating surfaces in different buildings.*

Assuming the furnace gases in both cases to be 650°, we have, for the steam, 650°—210°= 440 difference; and for the water, 650°—180°= 470 difference, or 12 per cent *in favor of the lower temperatures* at which the heat is recovered.

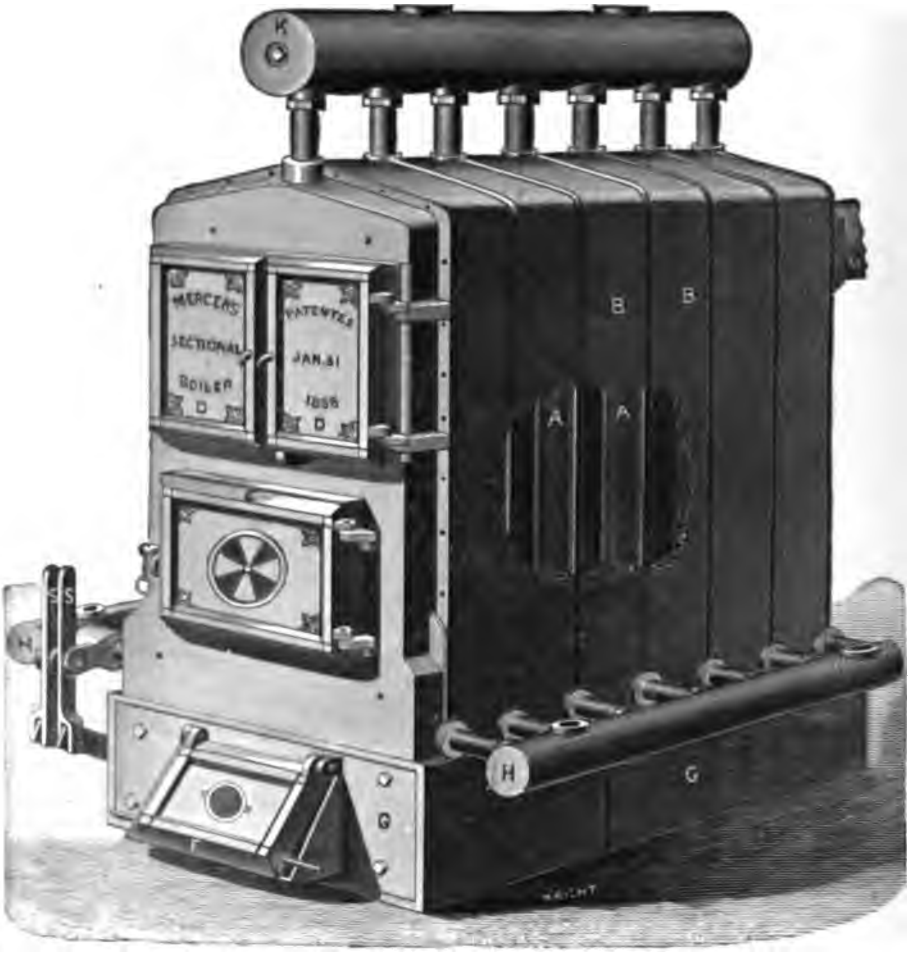
Crediting this estimate of 12 per cent, one foot of *water* surface should heat 50 + 6 = 56 lbs.; or if raised only 20°, from 170° to 190°, it should heat 112 *lbs. per foot per hour.* The coal required for the grate and boiler surface may now be stated — assuming that this class of *portable* heaters will recover and transmit 7,000 units per lb. of coal, and we burn 5 lbs. of coal per foot of grate per hour, we have 35,000 ÷ 2,000 units = 17½ *square feet of heating surface required per square foot of grate, and* 35,000 ÷ 300 *units* = 117 *square feet of radiator,* thus each foot of radiator may be counted as dispersing 1 lb. of coal each 24 hours (the outside temperature at 30° and inside at 70°.) This is equal to 168 lbs. of water heated 40°.

The mean of experiments by *Watt, Rumford,* and *Dr. Black* shows that 39 lbs. of water may be heated 180° by one pound of coal: 39 x 180 = 7,020 units ÷ 40 = 175 lbs. of water heated 40°.

THE MERCER BOILER.*

A WATER WARMING APPARATUS.

PLATE No. 23.



Proportion of Heating Surfaces in a No. 7 Heater.

Weight about 2,700 lbs.

Fire Surface	84 feet	Radiation Carried	350 to 400 feet
Grate Surface	3½ "	Proportion of Radiation to Grate, 1 to 214	"
A A, Sections.		H and K, Flow and return drums.	
B B, Jacket or covering.		S S, Shaking grate.	

* The H. B. SMITH Co., Manufacturers, Westfield, Mass.

INDEX OF CHAPTERS AND SUBJECTS.—VOLS. 1 AND 2.

VOLUME I.

PART FIRST.—Combustion Practically and Scientifically Considered.

VOLUME II.

BOOKS AND PAPERS CONSULTED AND REFERRED TO

ON HEAT.

Combustion . . . . W. E. Dimond (condensed in Part First).
Knight's Mechanical Dictionary . . . . First, Second, and Third Parts.
Appleton's Cyclopedia. *Tomlinson's Cyclopedia.*
Inorganic Chemistry . . . Thorpe, 1873, "Youman's Atlas of Chemistry," 1854.
Natural Philosophy . . . . Rolfe and Gillett, 1874.
A Practical Treatise on Heat . . . . Thomas Box, 1876.
Theory of Heat . . . . J. Clerk Maxwell, 1872.
A Simple Treatise on Heat . . . . W. M. Williams, 1880.
Heat as a Mode of Motion . . . Tyndall, 1873; "Heat," Chas. W. Williams, 1841.
Heat and Heat Engines . . . . . . Prof. W. P. Trowbridge; John Wiley, 1874.

ON FUELS.

Fuel; Its Combustion and Economy . . . . . . D. K. Clark; Van Nostrand, 1879.
Combustion of Coal . . . . Wm. M. Barr; Yohn Bros., Indianapolis, 1879.
Fuel . . . . J. Wormald, "Van Nostrand Science Series," 1874.
Petroleum and its Products . . . . S. F. Peckham, "U. S. Census Reports," 1885.
Liquid and Gaseous Fuels . . . . . "Scientific American" and other Journals.
Chemical Technology, Vol. I., Fuel . . . . Mills & Rowan, London, 1889.

ON STEAM BOILERS.

A Treatise on Steam Boilers . . . . Robert Wilson, London, 1873.
Steam Boiler Explosions . . . . Robinson; Little, Brown & Co., 1870.
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Illustrations of the Theory and Practice of Ventilation . . . . Reid, 1844.
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Warming and Ventilation . . . . Henry Ruttan, 1862; I. D. Smead, 1888.
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Our Dwellings Warmed and Ventilated . . . . J. W. C., 1875.
Ventilation . . . . Gouge; Van Nostrand, 1870, Lewis W. Leeds, 1880.
Steam Heating for Buildings . . . W. J. Baldwin; Jno. Wiley & Sons, N. Y., 1881.
Hot Water Heating and Fitting . . . W. J. Baldwin, "Eng. and Build. Rec.," 1889.
Ventilation and Heating . . . . Dr. John S. Billings, "The San. Engineer," 1884.
Steam Heating Problems . . . . "The San. Eng." N. Y., 1887.

MISCELLANEOUS.

Heating by Steam . . . . J. H. Mills, Boston, 1878.
Heating and Ventilation . . . . Schuman, 1877.
Report of the Mass. District Police . . . . Boston, Mass., 1889-1890.
Report on the Ventilation of the U. S. House of Rep., Robert Briggs, C. E., 1876, 1881.
Report of Prof. Trowbridge on the Relative Cost of Ventilation by Fans and Chimneys.
Health and Comfort in House Building . . . . . Drysdale & Hayward, London.
Report of the U. S. Centennial Exhibition . . . . Gen. F. A. Walker, 1876.
Proceedings of the Boston Academy . . . . Dr. Morill Wyman, 1858.
The Master Steam Fitter. *The Manufacturer and Builder* . . . . . Chicago.
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Scientific American and Supplements, N. Y.; *Modern Light and Heat*, Boston.

THE APPENDIXES OF VOLUMES I. AND II.

If the foregoing pages had been attempted only in the interest of the general reader, advertising matter, as such, would be out of place, or at least would detract from the solid and scientific character expected of books of this class. But as the writer has addressed himself equally to those who make, buy, sell, or use heating apparatus, it is clear that the manufacturer should be accorded a further representation than could be given in the editorial pages. The architect, engineer, and contractor should be informed where they can obtain the goods, machines, or methods which will yield the highest results. It should also be remembered that the interest and co-operation of enterprising manufacturers have alone made possible the large expenditure required to produce this work.

The portrait of Mr. C. C. Walworth (Frontispiece), it may be explained, was obtained as a favor to the author. It will also be acceptable to the many other friends and business acquaintances of the firm. The historical notes attached were furnished the author, but the other and personal matter was written after Mr. Walworth left Boston for California, and thus appears without his knowledge or revision. The early history of the House of Walworth and that of the older brother, Mr. James J. Walworth, will be found in the first volume, pages 320, 321. The dates were obtained from Mr. Walworth and Robert Briggs.

In the appendix, Volume I., will be found a fine steel-plate of the new works at South Boston, including view of Boston Harbor.

OFFICE OF HARDWICKE & WARE,

BUFFALO, N. Y., March 5, 1886.

MR. JOHN H. MILLS:

Dear Sir,— Probably no one, unless directly interested in the question of water and steam-heating apparatus, will appreciate the great importance to contractors and manufacturers of a compilation of data showing the relative value of the various means of producing heat, together with the comparisons of the various kinds of surfaces offered to the public, and knowing of the exhaustive tests made by you on these subjects, which as an impartial party you have been eminently qualified to do, we suggest that you put all this matter in shape for publication, and we feel sure it will be appreciated by manufacturers and consumers. The field is broad and needs what you can give, and for one, we can promise you our hearty support if you will undertake the work.

As I said to you at the time we took the page in your book we do not expect any returns from it as an advertisement, for it scarcely will reach the parties we can control, but we do it as a tribute to the worth of the author, and as a small pittance towards paying the debt of gratitude all Steam Heating Engineers owe to the years of indefatigable work, indomitable will, and never-failing energy you have spent on your work.

I do not flatter when I say that without such workers as you the heating business would stagnate and remain in the rule of thumb line it has so long lain in, for we who toil at the wrench and vise have no time while hunting the Almighty Dollar to stop and reason out the old, or follow new ideas, and unless some one has ambition enough to let the filthy lucre go, and work out these problems, we must all plow along in furrows that give no returns.

We hope that your book will be well received in the trade, and we wish you every success you so richly deserve.

Yours very truly, Hardwicke & Ware

OFFICE OF THE IRON REVIEW,

BUFFALO, N. Y., March 10, 1884.

JOHN H. MILLS, ESQ.

Dear Sir,—We would like very much to have an article from you for our next number, on either Ventilating or Steam Heating, to be received not later than 20th.

We are very particular not to publish anything which may be construed into a puff for any one's goods, but want items of news and importance, and we would not ask for this except as knowing you to be the most able authority in this city on the subject.

Yours truly, Homer E. Dudley & Co.

WASHINGTON ASYLUM,

WASHINGTON, D. C., March 7, 1885.

MR. JOHN H. MILLS,, BUFFALO, N. Y.

Dear Sir,— Have noticed your interesting articles on steam-heating and results of the experiments made with Walworth, Reed, Bundy and Detroit Radiators, published in the *Commercial Advertiser*, of Buffalo, February 23, 1885. Will you kindly inform me of the exact size, height, length and width of each Radiator, or the number of pipes or sections of the different kinds, and oblige.

Very respectfully yours, S. D. Tompkins

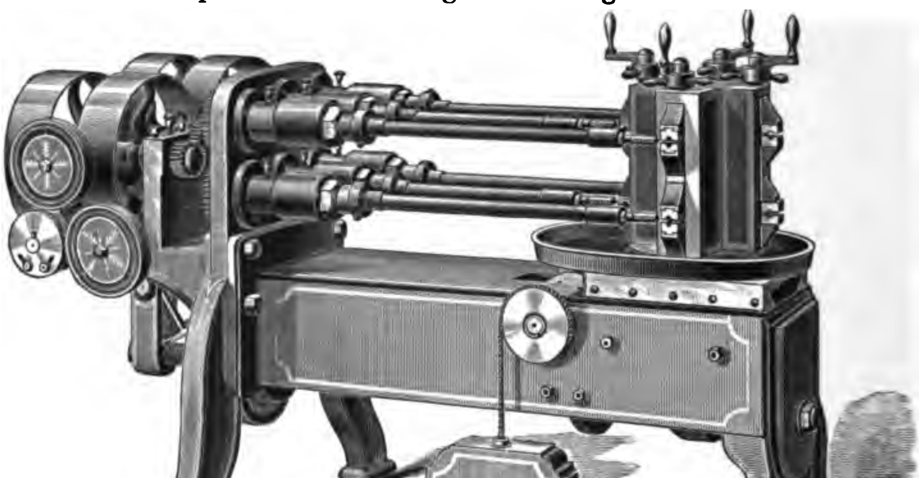
C. C. Walworth

For Biographical note see Appendix

For notes of the "rise and progress of this firm," see pages 320, 321.

Mr. C. C. Walworth was born in New Hampshire in 1816, where he had the usual school and academy chances for an education. This with teaching employed his time till of age. In 1836 he went West, and remained for several years, returning to be married in 1846. He was prosperous in agricultural matters, and accumulated a property which has since sold for over $100,000.

The next spring he engaged with Walworth & Nason in the business of steam heating. After three years, or in 1850, he took charge of the manufacturing department. Soon after this he invented and patented some very fine machines. The *six-spindle tapping machine* is here illustrated. With these machines about ten times the amount of work could be accomplished, and better than before. Besides being an inventor of the first order and a successful financier, he is one of the best men to handle labor; he has avoided all strikes and labor troubles; the men, finding that they are justly treated and promptly paid, have little cause for complaint. He became general manager in 1881.



Mr. Walworth has made many other valuable inventions in the line of his business, among which is his patent radiator; a manifold, which reduces the cost over the old-fashioned fittings and gives perfect control of the use of the steam; the patent *screw plate*, which to-day is the screw plate of the world, there being a large demand for them abroad; also a patent safety floor flange. In connection with Mr. O. B. Hall, he invented the Walworth Sprinkler, which has saved millions of dollars worth of property. See last page of Volume I.

Besides his own contributions to the mechanic arts, he has aided and stimulated others to make inventions of useful and valuable tools. The *Stillson* Wrench was one of these, and to the inventor the company have paid large sums in the way of royalty; while the well-known *Chapman* Valve was worked out at the factory in Cambridgeport, and had merit enough to succeed and float a stock company.

He early foresaw the necessity of having a foundry for casting malleable iron, and obtained a bond for a deed of the Malleable Foundry at Bradford, where he organized a company called the Malleable Iron Fittings Co. Mr. E. C. Hammer was chosen president.

The patents for the tapping machine were put in for $50,000; the balance was $75,000, making the company's capital $125,000.

All of Mr. Walworth's inventions were valuable, and gave quick returns. These profits he reinvested in shares of the company, so that in 1883 he had acquired a controlling interest, when there was a change of officers and directors, resulting in the present Board.

The rapid increase of the business of the Walworth company called for better and more extensive accommodations, resulting in the purchase of the Crystal Glass Works, at South Boston Point, containing some ten acres; four acres of the upland are fully used for the business. On this property is a fine store wharf, which is a saving of a large amount of freight. All coal, sand, and iron being landed above are dropped down through the roof into the bins where they are to be stored, and the iron simply carted to the cupola. This will melt forty thousand pounds of iron each day, and is used entirely in the business, the company doing no work for outside parties. There is a very fine foundry, with railroad to carry the iron when melted, saving the men much hard work, besides being able to do much more work for the same number of men. The buildings on this property had to be changed to meet the new business, and a new building four hundred and twenty-five feet long by sixty feet wide. (See last page of Vol. 1.)

Mr. Walworth is a remarkable man; although at this writing in his seventy-fifth year, he is in the enjoyment of good health, and carries the interests of his large and still growing company.

Having lost in 1887 perhaps the best wife that ever blessed a mortal's home on earth, he sorrowed long without hope, until it pleased the Father to reward his faith and show him a ray of light — "a silver lining to the cloud." This was a lady, also bereaved of her first and natural protector; what more natural and fitting result than that they should agree to comfort and cheer each other's lonely and remaining years? In short, they were married Nov. 14, 1889, and soon after, in truly youthful style, took the Pullman train to a land of winter fruits and flowers.

For late portrait of Mr. Walworth, see Frontispiece.

SPECIFICATION AND PRICE-LIST OF HORIZONTAL TUBULAR **STEAM** BOILERS,

MANUFACTURED BY BARTLETT, HAYWARD & CO., BALTIMORE, MD.

WITH MANHOLE IN DOME AND HANDHOLE IN FRONT AND REAR HEADS.

Diameter of Shell. . . . . Inches	24	24	30	30	30	36	36	36	42	42	42	48	48	48	48	54	54	54	54	60	60	60	66	66	66	72	72	72
Length of Shell and Tubes. Feet	6	8	6	8	10	8	10	12	10	12	14	10	12	14	16	12	14	16	17	14	16	18	14	16	18	14	16	18
Thickness of Shell . . . . Inches	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8
Thickness of Head . . . . "	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	7/16	7/16	7/16	7/16	1/2	1/2	1/2	1/2	9/16	9/16	9/16	9/16	9/16	9/16	5/8	5/8	5/8
Height of Dome. . . . . . . "	18	18	21	24	24	24	24	24	30	30	30	30	30	30	30	30	30	30	30	30	30	30	36	36	36	36	36	36
Diameter of Dome . . . . "	18	18	24	24	24	24	24	24	24	24	24	30	30	30	30	35	36	36	36	36	36	36	42	42	42	42	42	42
Number of 2½ Inch Tubes	14	14	23	23	23	34	34	. .	45	45	45																	
" " 3 " "	. .	. .	. .	. .	. .	28	28	28	38	38	38	49	49	49	49	64	64	64	. .	80	80	. .	91	91	. .	112	112	
" " 3½ " "	. .	. .	. .	. .	. .	. .	. .	. .	30	30	30	46	40	40	40	47	47	47	47	58	58	58	74	74	74	90	90	90
Horse Power (15 sq. ft. htg. surf.) with 2½ Inch Tubes	5.0	6.6	7.6	10.0	12.6	16.8	21.0	. .	24.0																			
" " " 3 " "	. .	. .	. .	. .	. .	14.0	17.6	21.2	23.3	28.0	32.6	29.3	35.6	41.6	47.6	45.4	53.0	60.6	. .	65.5	74.9	. .	74.3	84.9	. .	90.3	103.2	
" " " 3½ " "	. .	. .	. .	. .	. .	. .	. .	. .	21.8	26.0	30.4	28.4	34.0	39.8	45.4	39.8	46.4	53.0	56.4	56.5	64.6	72.7	70.9	81.0	91.1	85.2	97.4	109.5
Price with 2 or 2½ Inch Tubes . $	150	170	215	245	275																							
" " 2½, 3, or 3½ In. Tubes	. .	. .	. .	. .	. $	275	325	365	400	450	500																	
" " 3, 3½, or 4 " "	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. $	515	580	650	720	690	780	870	915	950	1060	1170	1100	1230	1360	1350	1510	1670
For Boilers without Dome *deduct*	$30.00		$40.00			$40.00			$50.00			$70.00				$90.00				$95.00			$120.00			$125.00		

HORIZONTAL TUBULAR **WATER** BOILER, WITH HANDHOLE IN FRONT AND REAR HEADS.

Intermediate and Additional Sizes as per Trade Circulars.

Diameter of Shell . . . . Inches	24	24	30	30	30	36	36	36	42	42	42	48	48	48	48	54	54	54	54	60	60	60	66	66	66	72	72	72
Length of Shell and Tubes . . . Feet	6	8	6	8	10	8	10	12	10	12	14	10	12	14	16	12	14	16	17	14	16	18	14	16	18	14	16	18
Thickness of Shell . . . . . . Inches	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8
Thickness of Head . . . . "	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	7/16	7/16	7/16	7/16	1/2	1/2	1/2	1/2	9/16	9/16	9/16	9/16	9/16	9/16	5/8	5/8	5/8
Number of 2½ Inch Tubes	24	24	44	44	44	66	66	. .	86																			
" " 3 " "	. .	. .	. .	. .	. .	50	50	50	68	68	68	94	94	94	94	118	118	118	. .	148	148	. .	172	172	. .	216	216	
" " 3½ " "	. .	. .	. .	. .	. .	. .	. .	. .	54	54	54	72	72	72	72	86	86	86	86	106	106	106	136	136	136	172	172	172
" " 4 " "	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	58	58	58	53	72	72	72	72	86	86	86	106	106	106	136	136	136
Heating Surface, Square Feet, with 2½ Inch Tubes	108	144	248	330	412	366	457	. .	590																			
" " 3 " "	. .	. .	. .	. .	. .	336	420	504	563	675	788	765	918	1071	1224	1143	1334	1524	. .	1659	1896	. .	1922	2196	. .	2394	2736	
" " 3½ " "	. .	. .	. .	. .	. .	. .	. .	. .	525	630	735	690	828	966	1104	984	1148	1312	1394	1404	1604	1805	1782	2036	2290	2233	2552	2871
" " 4 " "	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	640	768	896	1024	945	1103	1260	1339	1309	1496	1683	1600	1828	2057	2030	2320	2610
Price with 2½ Inch Tubes . . . . . $	120	140	170	210	250	250	300	. .	365																			
" " 3 " "	. .	. .	. .	. .	. $	250	300	350	360	420	480	500	580	660	740	700	800	900	. .	985	1105	. .	1180	1270	. .	1400	1570	
" " 3½ " "	. .	. .	. .	. .	. .	. .	. .	. $	355	415	475	485	565	640	720	665	755	845	890	920	1030	1140	1110	1245	1385	1380	1550	1715
" " 4 " "	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. $	485	565	640	720	670	760	855	900	920	1030	1140	1085	1215	1345	1355	1520	1690

New York Harbor.—Statue of Liberty and Brooklyn Suspension Bridge in the distance.

WORKS OF THE A. A. GRIFFING IRON CO., JUNCTION N. & N. Y. R R. AND MORRIS CANAL, JERSEY CITY, N. J.

DETROIT HEATING AND LIGHTING CO.

INCORPORATED IN 1887.

FACTORY AND HOME OFFICE, Detroit, Mich.	BERRY BROTHERS, Proprietors.	BRANCH OFFICE, 88 Lake Street, Chicago.

When the great fire of twenty years ago devastated Chicago, one of the few buildings not destroyed was that occupied by the Illinois Pneumatic Gas Machine Co. By reason of the general wreck and disturbance of business, it was, however, thought best to remove to Detroit, the headquarters of its principal stockholders, Messrs. Berry Bros., the well-known varnish manufacturers.

Since that time this company has attained a wide celebrity under the style of the Combination Gas Machine Co. The name might have been derived from the spirit of the management—the combination of Yankee skill and ingenuity in the evolution of the apparatus and the perfection of new devices with the Western enterprise and push which have planted these excellent machines in thousands of buildings all over the United States and Canada, as well as in South America and the islands of the South Pacific.

In the year 1887, Messrs. Berry Bros., having become interested in the heating business, opened negotiations with Mr. Geo. Bolton, of Peterboro, Ont., a heating engineer of over thirty years' experience, and owning a boiler of late and novel construction. His boiler had stood the severest tests of the intense cold of Montreal and the fifty-below-zero blizzards of Manitoba. The firm obtained the rights for the United States.

In the fall of 1887 they set up some half-dozen sample heaters in Detroit, and their manufacture in Detroit was soon afterwards begun. In 1888 this industry was united with the Combination Gas Machine Co., under the style of the Detroit Heating & Lighting Co.

In addition to the Bolton Heater and Combination Gas Machine this company make gas cooking, and heating stoves.

A new branch of the business is the manufacture of fuel gas plants, for which there is a growing demand among canning and meat-packing establishments, and wherever bronzing, welding, and light soldering are to be done. They are also dealers in gasoline for gas machines, in radiators, and other water-heating supplies. For description of the boiler and heating apparatus manufactured by this company, see pages 288 and 289.

THE H. B. SMITH COMPANY.

The foundation of the above company was laid in Westfield, Mass., in 1853, by Henry B. and Edwin Smith, brothers. They had a small foundry, the product being principally iron fences, and as the demand was limited, the business was supplemented by the sale of lumber.

This was continued until about the year 1860, when they became interested in, and commenced the manufacture of, Gold's Steam and Water Heaters, the invention of Samuel Gold, of Englewood, N. J., and William A. Fosket, of Meriden, Conn. In the following year the company began the sale, and erected this *first combined steam and water heating apparatus for warming residences and the smaller class of buildings.* They melted about three tons of iron per day into these boilers and their accompanying radiators.

In 1859 Mr. John R. Reed cast in his lot with the company, and was the able and devoted assistant of the Brothers throughout all the early years of their struggles, in the construction, sale, and erection of this *pioneer heating apparatus.* Under the combined push and pull of these three men, the business prospered, and by 1863 a new and larger cupola was required, and the output was raised to eight or ten tons per day.

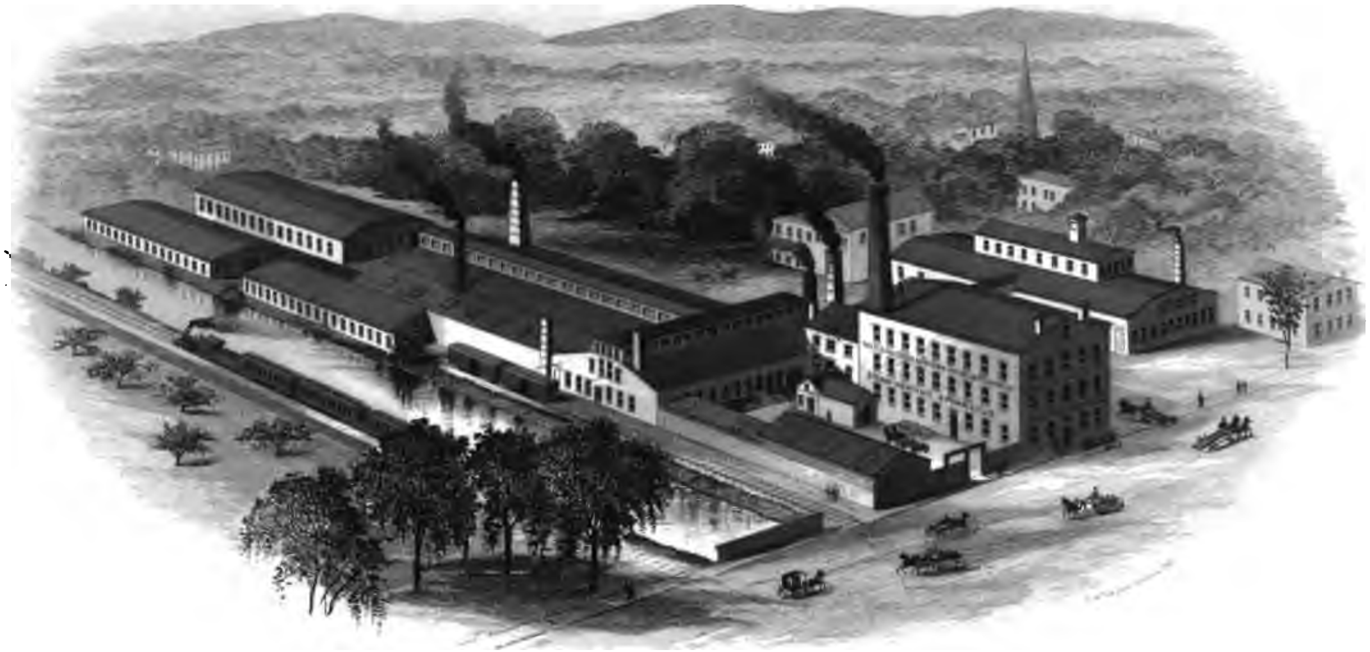
Thus matters continued, with varying growth, from 1872 to 1878, when there was a depression in this, as in many other lines of business, and it was found desirable to reorganize the firm, dividing and limiting the responsibility, and increasing the capital. It was at this time that John R. Reed became President and General Manager; Andrew Mercer, Vice-President; Phillip C. Smith, Treasurer.

About the year 1872 the company commenced the manufacture and sale of the Whittier Direct Radiator, an outgrowth and imitation of the Gold's pin extended surface, and in 1873, the Mills Sectional Safety Boiler; these being adapted for both high and low pressure, and thus for supplying steam for engines, they have for 16 years formed a staple and leading article of manufacture.

The demand for a better direct radiator being clearly outlined, Mr. J. R. Reed brought his practical and inventive mind to bear on the problem, and gave the company the "Reed Radiator," 1879, and, later, the celebrated "*Royal Union*" Steam and Water Radiator.*

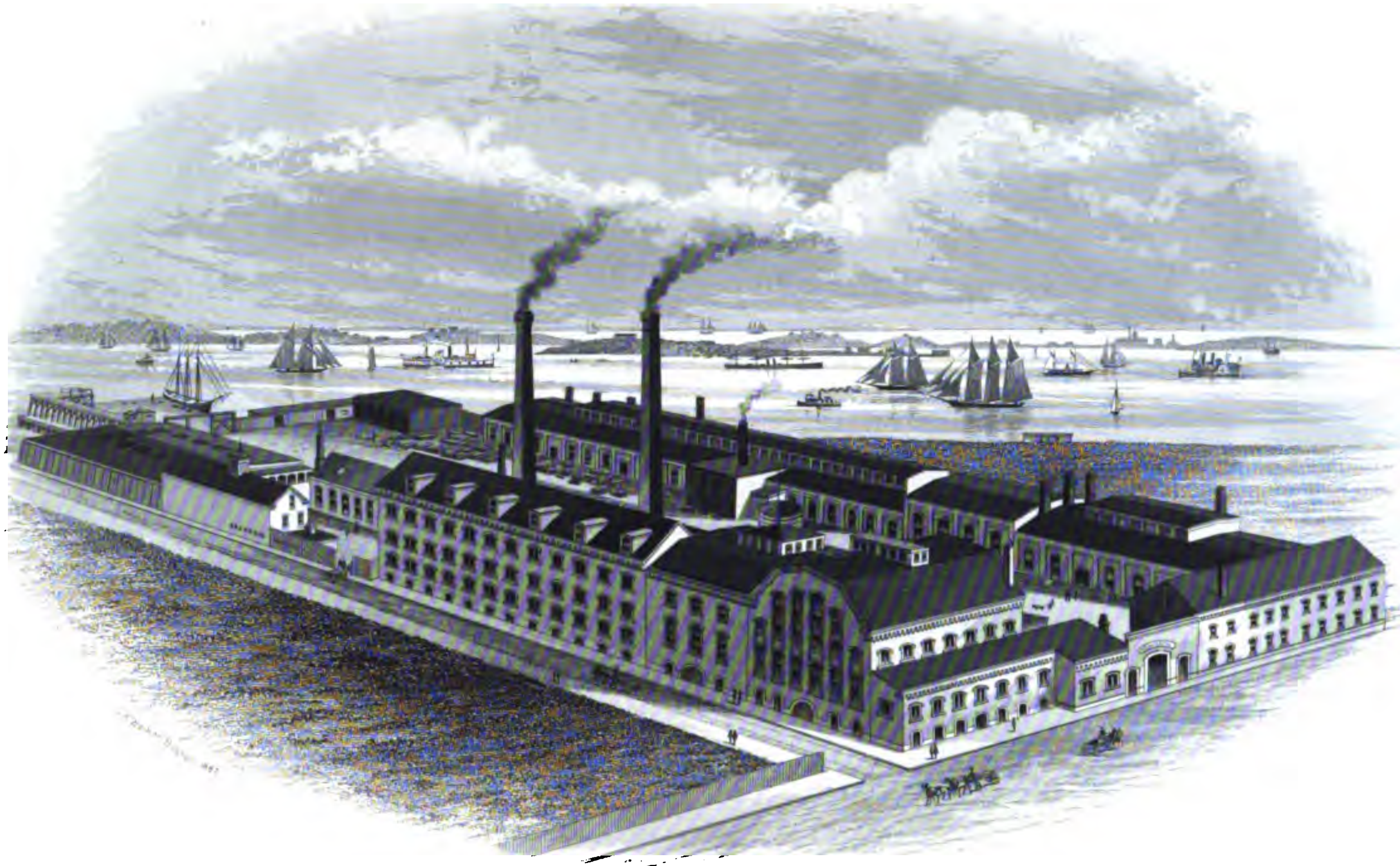
The approval of these inventions by the trade, induced them to extend their works by building a commodious foundry on the north side of Westfield River. The floor area is 50,000 square feet, and the plant can turn out 5,000 to 6,000 feet of direct radiators per day. The cupola capacity of both foundries is now 50 tons per day, and requires a working force of nearly 500 men.

* See last page of Volume I.



THE H. B. SMITH CO.

WESTFIELD, MASS. SOUTH SIDE.
BOILER WORKS.
ESTABLISHED 1853.



WALWORTH MANUFACTURING CO.

SOUTH BOSTON, MASS

U S A

STEEL AND IRON POLES

—— FOR ——

ELECTRIC RAILWAYS, ARC AND INCANDESCENT LIGHTING, TELEPHONE AND TELEGRAPH WIRES.

MANUFACTURED BY

WALWORTH MFG. CO., - - 16 Oliver Street, Boston, Mass.

Illustrated Catalogues, Price-Lists, and other information upon application.

See experiments and diagrams of actual duty on pages 580, 581, 582.

1